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CONDITIONS IN SOUTH AFRICA FOR ASTRONOMICAL OBSERVATIONS

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A SEARCH for an ideal site for astronomical observations has been in progress for many years. Although perfect conditions may be found nowhere on the earth, great differences undoubtedly exist. There is, especially, an increasing interest in the observation of the southern sky. Several observatories have been established in countries south of the equator, which are supported by local governments or institutions. The British government has long maintained a well-equipped observatory at Cape Town. The Harvard Observatory has carried on astronomical observations in Peru since 1889. Since 1923 the Observatory of Leiden, by special arrangement with the Union Observatory, has been extending its researches to the southern sky at Johannesburg. Also, the Yale Observatory is now establishing a branch station at Johannesburg, and the Detroit Observatory of the University of Michigan is about to erect a large telescope at Bloemfontein. Other observatories are interested in this problem. It is, therefore, of great importance to determine the most favorable southern site for astronomical observation.

The chief requisite for an astronomical station is a sky free from cloud, haze, dust and smoke. Since no locality is entirely free from clouds, it is desirable that the clouds which occur be distributed evenly throughout the year, rather than condensed into one decidedly cloudy season, such as prevails, for example, at Arequipa from December until March. There are other requirements, the chief of which, perhaps, is steadiness of the air. This is of great importance in both visual and photographic work. With marked unsteadiness a large telescope may have little or no advantage over a small one. An ideal site, also, would have freedom from strong winds, especially at night, a small diurnal range of temperature, at least a moderate altitude and accessibility, together with the necessities

FROM THE HILL NEAR THE UNION OBSERVATORY, JOHANNESBURG

and some of the comforts of modern civilization. Also, if a branch of a northern observatory, the station should be located so far south of the equator that the entire southern sky can be studied to the best advantage.

The Harvard Observatory, in 1887, received a fund left by Uriah A. Boyden, of Boston, for the establishment of an observing station at an altitude where the atmospheric conditions would be especially favorable. It was clearly recognized that such conditions would not be found at existing observatories, which were at that time generally situated near large cities. Under the general direction of Professor Edward C. Pickering, then director of the observatory, investigations were made of various sites in the United States and along the west coast of South America. As a result of these studies, after a year of preliminary work near Lima and in Chile, the well-known branch of the observatory at Arequipa, Peru, was established, where observations have been carried on regularly until the present time.

Although Arequipa had proved to be a fairly satisfactory site, judged by the results there obtained, the amount of cloud was often large and its distribution unfortunate. It seemed worth while, therefore, to learn whether the southern hemisphere offered elsewhere a better location than Peru. The semi-arid belt of small rainfall which lies across Peru and northern Chile crosses the high plateau of South Africa. The same belt extends also over Australia, some parts of which may have extremely clear skies.

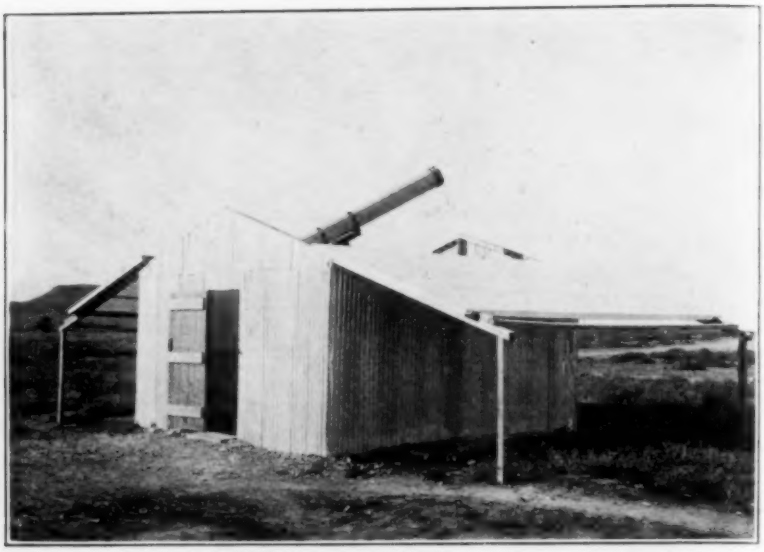
Very favorable reports had been received concerning South Africa, and it was chosen for investigation at that time. The gen-

THE FRANKLIN-ADAMS TELESCOPE
Union Observatory, Johannesburg, with Dr. Innes and Mr. Wood.

eral climatic conditions of the region were fairly well known from observations carried on under the direction of the Meteorological Commission of the Cape of Good Hope and the governments of the other colonies which now make up the Union of South Africa. At many of the stations, however, cloud records were few, or entirely lacking, and no study of the steadiness and transparency of the air had anywhere been made. Under these circumstances I was asked to make a year's study of the region and left Cambridge on November 17, 1908. In England consultations were held with Sir David Gill and Sir William Morris, at that time the highest authorities on the climate of South Africa.

Cape Town was reached on December 22. As a place of residence Cape Town is charming. The scenic effects are very striking. The city lies along the curving shores of Table Bay and immediately at the foot of Table Mountain which rises abruptly to a height of 3,500 feet. The suburbs are also especially attractive, made more so by the fine groves of oak planted long ago by the Dutch settlers. The Royal Observatory is situated a few miles from the town. Although much valuable astronomical work has been accomplished at this observatory, the site on comparatively low ground near the sea seems unfavorable.

If we except the more or less narrow coast lands lying near the South Atlantic and Indian Oceans, South Africa is a vast tableland. Included in the coast regions are rich and fertile areas having sufficient rainfall for the purposes of agriculture. In general,



HARVARD TEMPORARY STATION, HANOVER

however, irrigation is necessary. The conditions vary enormously, often within short distances, owing to the influence of adjacent or intervening mountains. From Cape Town going by rail to the northeast one passes successively through the southern Karroo, having an elevation of about 1,500 feet, then through the middle Karroo, having a somewhat greater elevation, until the Great Karroo is reached which extends northward at an elevation of from 4,000 to 6,000 feet. These great interior regions are semi-arid, but they vary much in different localities. In the west, especially, are stretches of almost complete desert, while in other parts considerable rainfall occurs. Only a scant population is possible, unless under artificial conditions such as those brought about by gold and diamond mining. In general, the region is suitable for grazing rather than for agriculture, except in the comparatively insignificant areas where irrigation can be employed. The soil is good, but not only is the rainfall scant and irregular, but it frequently comes in heavy downpours, the accompaniment of violent thunder storms; so that, in addition to the loss of water, which runs away rapidly over the sun-baked earth and is lost, great damage is caused by erosion. The vast stretches of plain, generally known as *veldt*, are parched and apparently dead in the dry season, but are often green and beautiful in the rainy season. Each farm must have its natural spring (*fontein*) of water for domestic and farm purposes. This is frequently supplemented by dams constructed at large expense to retain the rainfall, and sometimes by artesian wells. These great farms support thousands of sheep and cattle which subsist without

A Street in Hanover

difficulty on the sparse bush and grass of the veldt, provided there is an abundance of water for drinking. In exceptionally dry years, however, the supply may fail and then the cattle perish in great numbers. Farther north in Rhodesia is a region of greater rainfall and much more pleasing appearance. Instead of arid plains beautiful groves of trees are interspersed with grassy glades.

Somewhere on this great plateau was to be found the locality most suitable for astronomical observation, and the first step appeared to be to take a general view of the different parts. Cape Town was left, not without regret, and Worcester was reached in a few hours. This small city, 109 miles from Cape Town, at an elevation of 800 feet, is perhaps the most desirable site for astronomical work near the coast. It is situated in a large arid valley not far from the base of the Hex River Mountains. It is well supplied with water brought from the Hex River, a tributary of the Breede River. The valley is surrounded by mountains rising from 3,000 to 6,000 feet. The climate is in general very agreeable, although somewhat hot in summer. Occasionally the temperature attains 100° F. A maximum even as high as 104° has been recorded. In winter the temperature rarely falls to the freezing point.

The next site to be seriously considered was Hanover, four hundred miles to the northeast on the Great Karroo at an elevation of about 4,500 feet. The train by which this trip was made was of the English compartment class, and comfortable when not crowded. One is much impressed with the vast stretches of arid lands apparently but little inhabited. For hundreds of miles no town of much

THE VILLAGE OF HANOVER

importance is passed. Although the large farms generally lie in the background out of sight, the amount of business they do with the railway must be small, if one can judge by the appearance of the stations along the railway. In such a country one train a day is sufficient for all the passenger traffic, and this goes forward by night as well as by day. This involves the possible arrival at one's station at any hour of the day or night. My train reached Hanover Junction at 12:30 A. M. From the junction to the village of Hanover is nine miles. This trip was accomplished at that time in a "Cape cart," a two-wheeled wagon having two seats, the one in front for the driver and a possible passenger. The wheels of the Cape cart are very large and the body correspondingly high. A Boer lady shared the rear seat with me. We were so completely shut in by the low cover, the closed sides, and the persons in front, that even by daylight it would have been difficult to see anything of the scenery. As it was, I could not even see the faces of my companions. The cart was drawn by horses over a road by no means smooth, and one hesitated to conjecture what would be the result of an overturn. Apparently this never occurs. We arrived at the only hotel in Hanover at about two A. M. Not a light was anywhere visible. The driver opened a door on the porch, lighted a candle and left me. This seemed rather an unceremonious entry, but as there were two beds in the room, I selected one and retired. On the following day the proprietor and his wife appeared and did all in their power to make my stay comfortable.

"KOPJES" AND "VELDT"
Hanover in the background.

Hanover is a small town on the Great Karroo, about 500 miles distant from Cape Town by rail. It lies in the midst of a nearly level expanse of semi-arid veldt. At the time of my visit it had perhaps 500 white residents and about as many black inhabitants. The latter were referred to as Kaffirs, although their racial characteristics were somewhat mixed. The Kaffirs lived in a section by themselves known as the "location." At nine P. M. a bell was rung and they left the town proper and were not expected to return until after daylight the following day. Upon one extremely tall and slender policeman rested the obligation to enforce this and all other laws. Good order was everywhere maintained. During my residence in South Africa I wandered about in this and other towns at all hours of the day and night without the least affront. In Hanover it was not considered respectable to keep the Kaffirs in one's house, even in the case of domestic servants. The village itself was rather picturesque and attractive with its brick or whitewashed houses placed in large gardens.

The early Boers were a rude but heroic race. Incensed by what they regarded as the tyranny of the British government at Cape Town, they "trekked" into the little known regions to the east and northeast, fighting their way against black savages and always comparing themselves to the Children of Israel in their flight from Egypt to the Promised Land. In their migrations each natural spring of water became the site of a household. Without this spring the development of a farm home would have been impos-

A SOUTH AFRICAN FARM
Hanover district.

sible. Hanover owes its existence to an unusually abundant spring. This is situated on a low hillside near the village and provides a daily supply of about 250,000 gallons, an amount which varies little, whatever the season. Originally the water flowed to the town in an open stream and every family went to this stream for its household needs, and the balance was used for irrigation. Owing to a serious epidemic of typhoid fever, which occurred before my arrival, caused probably by a pollution of the supply, the spring was closed in and the water was piped to the town. Even then no pipes were allowed to enter the houses for fear lest some families might use an unfair amount of water. Faucets were placed in the streets, however, where each family might obtain sufficient for domestic use. The balance, a small but continuous supply, was devoted to the irrigation of the gardens. Each original proprietor was allowed this limited amount for a certain hour of the day or night once a week. More recent householders residing in the outskirts of the town received none of the water for irrigation, but in some cases availed themselves of shallow artesian wells which provided a rather limited supply. It is hard to see how a larger population could be provided for, unless possibly by better artesian wells.

At this time a visit was paid to Bloemfontein, where the conditions appeared to be similar to those at Hanover. Bloemfontein, however, as the capital of the Orange River Colony, had much to offer in the way of social and educational advantages. Kimberley

A Boer Family on the Move

was also visited. It lies about two hundred miles north of Hanover and to the west of Bloemfontein. Except for the presence of the diamond mines which cause the ground in their vicinity to be torn up by the open workings, and the uncertainty as to the future of such a region, the conditions appear to differ little from those at the other towns referred to. The same may be said also of Johannesburg, which has the advantages which go with a large city and especially the presence of an established observatory. As one goes farther north the cloud and rainfall slowly increase. The trip was extended to Buluwayo in Rhodesia, a much fairer country than that to the south.

While at Buluwayo a visit was made to the Victoria Falls, a short distance to the northwest. The Zambesi is the largest river in this whole region. It flows through a forested country in a generally easterly direction along the plateau. The falls are caused, not by any falling off in the level of the plateau, but by an enormous transverse cleft or chasm lying in the path of the river which is here about a mile in width. The chasm is nearly 400 feet deep and its width is about as great as its depth. Confined in this narrow gorge, the waters of the river have for exit only a narrow opening, in one place about 300 feet in width. This outlet is known as the cauldron. Below the falls the cañon through which the river runs is narrow and tortuous. The roar of the cataract is audible for many miles, and the mists which rise above it can be seen from a long distance. It is easily one of the world's scenic wonders. An observatory founded near this great natural phe-

A Kaffir Chief and his Family

nomenon might perhaps be invested with a certain romantic sentiment. The region, however, is evidently more cloudy than the barren plateau a thousand miles to the south.

A somewhat hasty survey of the whole region having thus been made, it became necessary to decide upon the site of the main station for the year's program. Hanover was selected for the following reasons: In the first place, in the opinion of Sir William Morris, who had made observations for geodetic purposes over the whole region, Hanover offered the best conditions of all the places which he had visited. From a purely astronomical standpoint, this view was shared by Dr. R. T. A. Innes, director of the Johannesburg Observatory. No one whom I consulted believed that Hanover was surpassed in this respect by any other locality, although other sites were thought to be about the same. For a permanent observatory some weight should probably be given to such considerations as the advantages of a large city and the presence of an established observatory, such as that at Johannesburg. For our temporary expedition such considerations were of less importance. Rhodesia was rejected, since undoubtedly it was more cloudy than the region farther south. Kimberley was considered unfavorable on account of the vast diamond workings, and Johannesburg on account of the still vaster gold-mining activities. Bloemfontein and Worcester were chosen as secondary stations, and arrangements were made for occasional trips to these places in order to test the seeing and to assist in the observations. Voluntary services of great value were given in the former place by Mr. James Lyle, and in the latter place by Mr. Izak Meiring.[1] Hanover is situated conveniently between these two towns.

Regular work was begun at Hanover early in February, 1909. In addition to the meteorological observations, astronomical observations of southern stars were carried on, not only for the results themselves, but as the best possible test of the astronomical conditions. A small observatory was established on the edge of the town without expense for the site through the kindness of a local club. The equipment consisted of an 8-inch visual telescope, a 5-inch visual telescope, and a small photographic instrument devoted chiefly to long exposures on the southern Milky Way. In addition, for use at the three stations, photographic instruments were provided with which equatorial stars were photographed each clear night as a test of the clearness and steadiness, and exposures were

[1] In addition to those whose names are given in the text and others, the thanks of the expedition are due especially to H. E. Sir Walter Hely-Hutchinson, then Governor of Cape Colony, and to the officials of the British South Africa Company.

BLOEMFONTEIN. RESIDENCE OF MR. JAMES LYLE.

made for several hours on polar stars as a check on the cloudiness. Altogether at the three stations about 1,500 plates were obtained.

The mayor and other Dutch officials of Hanover received me with cordiality, and the few English and Scotch residents were most hospitable and kind. My life there, which otherwise would have been somewhat lonely, was made so pleasant that it stands out as one of the especially bright spots in my life in foreign countries. So much so that even now the thought of that lonely little town almost lost on the wide expanse of veldt, and of those who received me in such a cordial and informal way, causes an odd quickening of the heart.

The pastor of the Dutch Reformed Church did not call, and I inferred from various reports that he had serious doubts as to the reconciliation of science and religion. The pastor of the colored church called, however, and without revealing his identity asked me many questions about the instruments and work. He made few comments, but later preached a sermon in which he advised his congregation to keep away from the observatory, a bad and even dangerous association for Christians.

In Hanover an astronomer was an unheard-of novelty. I became known at once as "The Professor." A lady of my acquaintance remarked to her small sons one day, "Here comes Mr. Bailey." "Oh, no, it isn't," replied one of them, "that is The Professor." The professor was reputed to be able to foretell all sorts of natural phenomena, a reputation very difficult to maintain.

BLOEMFONTEIN FROM SIGNAL HILL
Showing Brandkof, a hill suitable for an astronomical station.

In common with other small South African towns Hanover was afflicted with house flies during the hot season. Sanitary conditions were not of the best. In the hotel where I lived flies swarmed from outside into the dining room, since neither windows nor doors had screens. It was necessary to eat with one hand and to brush away the flies constantly with the other. A lady remarked to me that in spite of the greatest care she could always feel flies buzzing about in her stomach.

Occasionally for exercise I walked entirely around the village on the open veldt, and sometimes a small but exceedingly fleet deer was seen. At that time game had been preserved to some extent and partly domesticated on the great farms, where it was systematically hunted at stated seasons.

The following table gives the results for the night cloudiness at Worcester, Hanover and Bloemfontein, as derived from the photographs of equatorial and polar stars. The months have been placed in their usual order, but the observations really extended from March, 1909, to February, 1910, inclusive. The surprising equality in the cloudiness recorded for the three stations is the most striking feature. While this accordance is doubtless greater than would generally be found in the results for any one station in different years, and hence is partly accidental, it seems certain that there is little to choose between the three stations in the matter of cloudiness. The mean cloudiness at Hanover at eight P. M., was 3.8.

The result for the whole twenty-four hours would differ slightly from these values. It should be noted that while the cloudy and rainy season at Hanover and Bloemfontein is in the southern summer, at Worcester no such distinction is found. If means values for a series of years were used it is probable that the resulting cloudiness would be nearly uniform throughout the year. This result might be expected, since Worcester is situated between Cape Town, where the cloudy season is in the southern winter, and the towns on the Karroo, where it occurs in the summer. For the same year the mean cloudiness for Arequipa was 5.6, the different months ranging from 3.0, July, to 9.2, December. On the scale employed, 0 indicated a clear sky, and 10, one completely cloudy.

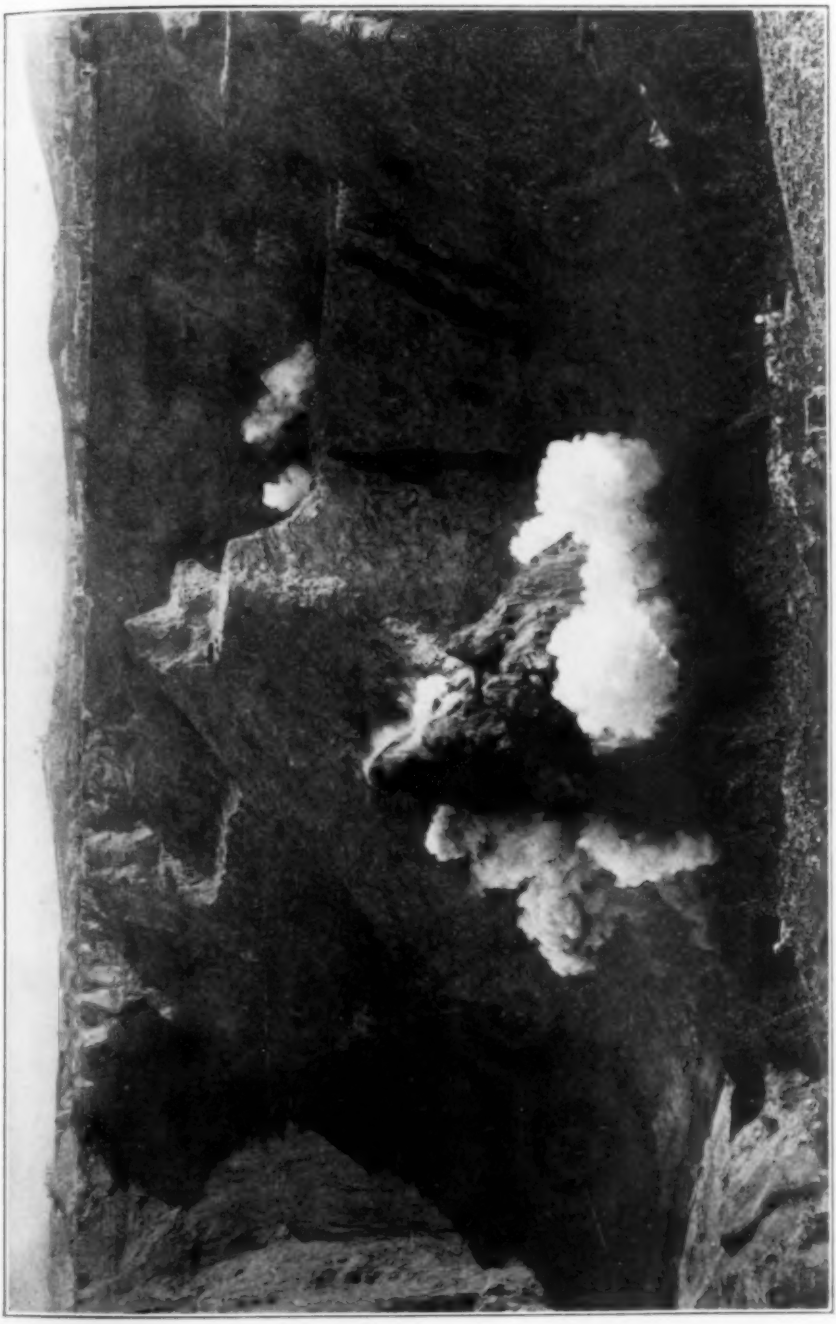
TABLE 1

SOUTH AFRICA. NIGHT CLOUDINESS. MARCH, 1909, TO FEBRUARY, 1910

Month	Worcester	Hanover	Bloemfontein
January	2.2	4.0	4.0
February	4.1	6.0	4.7
March	3.6	3.4	4.3
April	3.3	2.8	2.4
May	2.8	3.4	4.1
June	3.2	2.2	1.3
July	2.7	1.4	1.6
August	3.5	2.7	2.9
September	3.4	2.6	2.3
October	4.7	3.1	3.6
November	3.7	3.6	4.1
December	3.8	5.9	4.3
	—	—	—
Means	3.4	3.4	3.3

Table II gives, for the same months as in Table I, the results of the observations of temperature at Hanover, expressed in degrees Fahrenheit.

The diurnal changes in temperature at Hanover as shown in the table are severe. The records of the mercurial thermometers are in general checked by the records of the thermograph, although the range is a trifle less by the latter instrument. The thermometers were read at two P. M. and at eight P. M., since the observers often worked until late at night and were not on duty in the morning, but details of the changes are available from the thermograph sheets. During the winter the temperature in the late night often fell to 20° F. and in a few cases to 14° F. By afternoon of the following day it sometimes rose to 60°, or even to 70°. In summer, while the days were often very warm, heavy clothing was needed in the late night. On this account the people of Hanover, who in general were without the means for providing their homes with



KIMBERLEY. DIAMOND MINE: BLASTING THE "BLUE ROCK"

TABLE II

SOUTH AFRICA. HANOVER. AIR TEMPERATURE

Month	Max.	Min.	Mean Max.	Mean Min.	Daily range Max.	Daily range Min.	Daily range Mean
January	100°	40°	88°	54°	47°	20°	34°
February	92	45	83	55	40	10	28
March	84	39	77	48	42	22	29
April	82	31	73	45	42	8	28
May	72	26	65	37	41	8	28
June	68	14	64	28	49	8	36
July	69	14	62	25	50	18	37
August	80	16	68	28	55	18	40
September	89	18	73	36	53	19	37
October	90	26	77	39	55	23	38
November	93	36	84	44	51	12	40
December	95	42	84	49	52	13	35

artificial heat, retired early in the evening to escape the cold, and became active again only after the morning's sun had made life more comfortable. There were no street lamps, thus making the locality ideal for astronomical observations. During the daylight hours the relative humidity was generally rather low, often no more than 30 or 40 per cent., or even less, but at night it rose rapidly in a few hours to 90, or even to saturation on unfavorable nights. Under such circumstances the deposition of dew or frost caused considerable inconvenience. This trouble was aggravated by the exposed condition of the instruments, which were unprotected when the sliding roofs of the shelters were removed. In some cases the steel tube of the 8-inch telescope was covered with a thin coating of ice.

A mean diurnal range of temperature, varying in different months from 28° to 40°, with a yearly mean of 34°, seems somewhat extraordinary. It is probable that the year during which these observations were made was one of exceptionally large extremes, and that in general somewhat milder conditions might be expected. The general truth of these results, however, is checked not only by the records of the thermograph but by observations made under the direction of the Meteorological Commission of the Cape of Good Hope in other years. The annual mean diurnal range is nearly always greater than 30°. The extremes appear to be much greater at Hanover than at Worcester, as might be expected, but also larger than at Bloemfontein. At Worcester during two years' observations made by Mr. Meiring, the maximum temperature was 104° and the minimum, 31°. The mean daily range for the two years was 25°, varying between 31° in January and 19° in August. In Bloemfontein the highest temperature found in several years' rec-

VICTORIA FALLS. THE CAULDRON

ords was 99°, and the lowest 22°. The mean daily range appears to be about 27°, although the results depend on self-recording instruments.

In the vicinity of Hanover are several small hills rising abruptly from the plain like plums in a pudding. They are known as "kopjes." One of these, having an altitude perhaps of 250 feet above the plain, is situated at a distance of about a mile and a half from the village to the northeast. Some temperature experiments were made on the flat summit of this hill. Two thermographs were available for a comparison of the temperatures on the hill and on the level plain near the observatory. They were adjusted to read the same at 50°. From March 16 to May 10 one of them was placed near the observatory, and the other, on the summit of the hill. From May 11 to August 1 the instruments were interchanged.

The second period was largely during the clear winter season. Altogether, they give a fairly good test of the advantages of a site somewhat elevated above the plain. The mean results are shown in Table III.

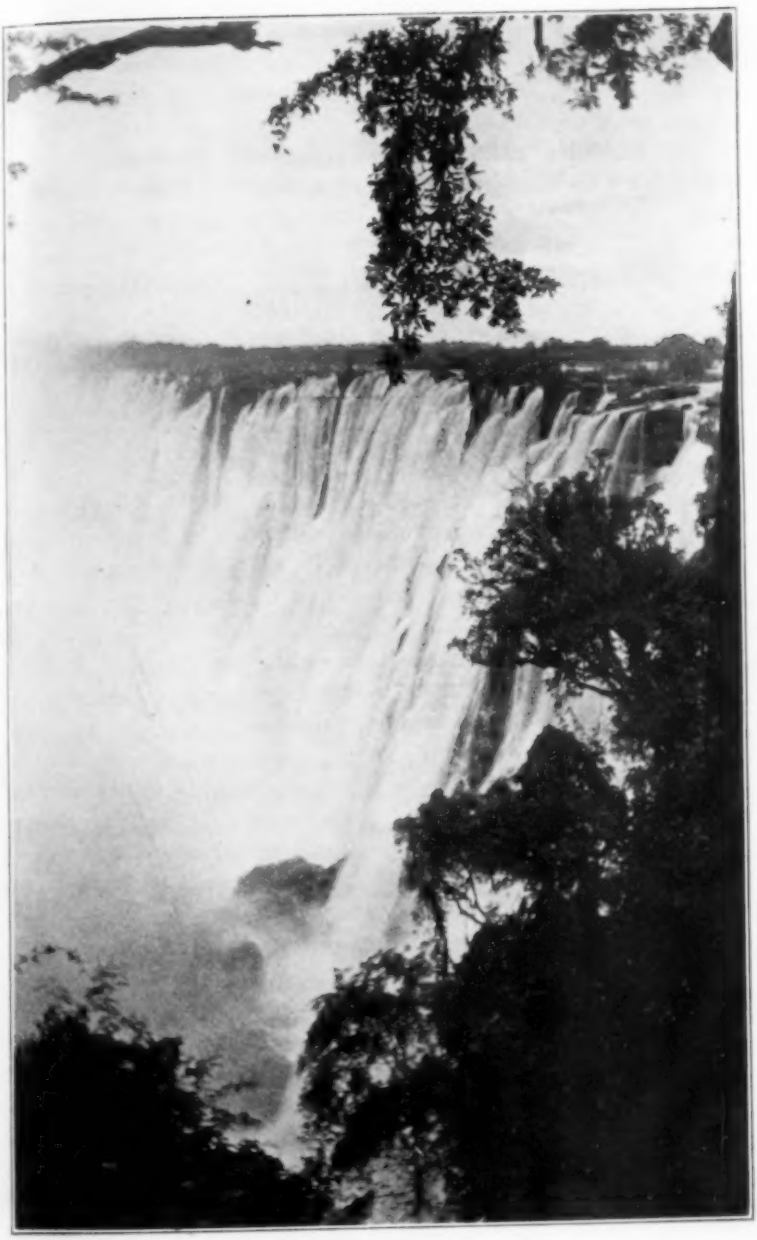
TABLE III

SOUTH AFRICA. HANOVER. TEMPERATURES, TOWN AND HILL

Maximum		Minimum		Range		
Town	Hill	Town	Hill	Town	Hill	
°	°	°	°	°	°	
72.3	70.7	46.8	49.0	25.5	21.7	March 16 to May 10
62.7	60.7	29.9	38.1	32.1	22.6	May 11 to August 1
67.5	65.7	38.4	43.6	29.2	22.2	Whole period

The advantages of a site on the summit of a hill appear to be considerable. During about four and a half months, the maximum temperature was higher on the hill than on the veldt on only two days, and the minimum temperature was lower on nine nights. The maximum temperature was the same at both stations on twenty days and the minimum the same on thirteen nights. On all other occasions the maximum was lower and the minimum higher on the hill, thus giving a mean daily range of temperature for the whole period less by about 7° than that on the plain.

Many observations to determine the quality of the "seeing" were made in different localities. The scale devised by Professor William H. Pickering was used. It is described in Harvard *Annals*, *82*, 31. It runs from 1 to 10, 1 being used for extraordinarily bad conditions when the star's image is very large and shows no diffraction disc or rings, and 10, when both disc and rings are sharp and stationary. The scale is intended for use with a five-inch telescope and a one quarter-inch eyepiece. I have seldom, if ever, seen definition which seemed to me to deserve 10. Observations were made at Worcester on nine nights in various months. The best conditions observed were recorded as 8, the average for stars of altitude 30° or more being 6.4, and the lowest for such stars 5. Near the horizon the poorest record was 3. At Hanover observations were made on twenty-five nights. The best seeing was recorded as 9, which often occurred. The average for stars above 30° was 7.7, and the poorest for such stars 5. Stars near the horizon were called 3 in a few cases, but usually 4 or higher. At Bloemfontein observations were made on ten nights. The best seeing was called 9, the mean for stars above 30°, 7.3, and for stars near the horizon sometimes 3 but usually 4 or higher. A few observations also were made at various other localities. At Johannesburg the seeing, so far as can be judged by observations on two nights, compares favorably with that at Hanover and Bloemfontein. At Buluwayo the seeing was fair but somewhat less favor-



VICTORIA FALLS
From the northern bank.

able. At Cape Town the seeing was inferior to that in the other places examined. The highest record was 7, and at times the record was from 1 to 4. It should be stated that observations were made on only three nights and these in December. A southeast wind seemed to affect the seeing badly.

In addition to the amount of cloud, the polar and equatorial plates made at Worcester, Hanover and Bloemfontein served for a determination of the transparency of the atmosphere. The examination shows no perceptible differences between Hanover and Bloemfontein. Equally faint stars appear on the photographs at these two stations. At Worcester, however, there is shown a distinct loss, compared with the other two stations, amounting to half a magnitude or more. This photographic result confirms visual observations. That the sky is darker and the stars more brilliant on the plateau than at a lower altitude near the coast has been observed by many. Worcester has considerable in its favor for an observer who does not need the utmost possible in the way of faint objects. The atmosphere is undoubtedly less transparent than on the plateau, but on the other hand the amount of cloud is small and is more evenly distributed throughout the year than at either of the other stations. The climate is mild and the city offers all necessary advantages for comfortable living. It is not far from Cape Town. Expenses would probably be less than elsewhere, both for installation and maintenance.

The high plateau of South Africa offers many inducements for the establishment of an observatory for the study of the southern sky. The conditions are good over a wide area. If such an observatory insists on the social and educational advantages of a large city, Johannesburg will be chosen. It has also the added attraction of the presence of the Union Observatory.

Hanover and Bloemfontein appear to be more or less equal from the purely astronomical standpoint. The cloudiness and transparency of the atmosphere are about the same. The extremes of temperature may be considerably larger at Hanover, although these might be avoided in part by the selection of a site on the summit of a hill. The seeing may be a little better at Hanover and dust storms less frequent. Taken from all considerations, however, Bloemfontein seems preferable and is probably not surpassed by any other locality in South Africa as a site for an astronomical observatory.

RADIO TALKS ON SCIENCE[1]

FERTILIZERS FROM THE AIR

By Dr. F. G. COTTRELL

FIXED NITROGEN RESEARCH LABORATORY, U. S. DEPT. OF AGRICULTURE

OUT of the 87 chemical elements known to us only about a dozen enter into the composition of most plants, and of this dozen there are only three which ordinarily come into consideration in the fertilizer problem, as the others are almost always available to plants in sufficient quantities. These three elements in which the whole fertilizer problem centers are phosphorus, potassium and nitrogen.

Phosphorus and potassium were widely and generously distributed in the igneous rocks of the earth's original crust and they have come on through and are found in larger or smaller proportions almost everywhere. Their story as normal soil constituents is therefore essentially a mineralogical one.

The case of nitrogen is, however, quite different. The two atoms of nitrogen making up the molecule of this inert gas which constitutes four fifths of our atmosphere have such a tremendous affinity for one another that it is only under very special conditions that they can be separated and made to combine with other elements to form compounds which can enter into the soil and be taken up by plants. This process, however, is absolutely necessary to life as we know it on the earth, because none of the plants with which we are ordinarily familiar seem to have the power in themselves of directly utilizing the free and chemically uncombined nitrogen in the air which lies all about them but must rely wholly on absorbing it in compounds through their roots.

On the other hand, when we try to trace back to their source the nitrogen compounds in nature, whether these be in the so-called humus of the soil, the coal measures, the petroleum beds or the nitrate deposits of Chile, we almost invariably find the trail leading us to a vegetable origin.

Thus we are brought to the seeming paradox that combined nitrogen in nature is all of plant origin and yet plants as we know them are incapable of forming compounds out of the nitrogen of the atmosphere which is apparently the only original source of the element.

[1] Broadcast from Station WCAP, Washington, D. C., under the auspices of the National Research Council and Science Service and the direction of Mr. W. E. Tisdale.

Like most paradoxes the answer to this one is to be found in the limitation of our acquaintance with the facts. Plants as we ordinarily know them are only a part of the vegetable kingdom. There is a vast host of marvelously important plants all about us, the individuals of which we can never see except under a powerful microscope, and it is through certain very definite species of these, the so-called nitrogen-fixing bacteria, that we now believe practically all the millions upon millions of tons of chemically combined nitrogen on earth have been slowly built up through the ages, out of the chemically free or uncombined nitrogen of the air.

It must be remembered, however, that the bacteria, though belonging to the vegetable kingdom, contain none of the green coloring matter called chlorophyl so can not derive their necessary life energy from sunlight nor build up starch or sugars out of water and the carbon dioxide of the air as do green plants. They must, on the other hand, subsist on such compounds built by the green plants and in exchange pass on to these latter the nitrogen compounds so essential to all.

Thus we see here again beautifully illustrated the endless interdependence of everything in nature.

Among these nitrogen-fixing bacteria, we find it convenient to distinguish two chief classes. The one (typified by the genus azotobacter) grows freely in most soils independent of any particular species of other plants, but it feeds upon the organic matter of the soil and ordinarily consumes the equivalent of from fifty to five hundred times as much sugar or starch as the weight of nitrogen which it "fixes" or puts into combined state from the air. The other class (typified by the species radicicola) will grow and thrive only on the roots of certain higher plants, namely, the legumes or pea family. In this case the green plant or host draws not only its own energy from the sunlight, but also that needed by the bacteria and passes this on to the latter in the form of food, receiving in return its quota of nitrogen compounds.

Under average soil conditions the azotobacter type of organism in the course of an ordinary growing season probably adds something like five to ten pounds of nitrogen per acre to the soil, whereas radicicola growing vigorously on the roots of a good field of peas, beans, clover or alfalfa may fix ten times this amount. Both forms are almost universally present to some extent in all soils and thus like any other crop only need to be given favorable conditions to multiply and furnish a large yield of fixed or combined nitrogen.

The old Romans, even though they knew nothing of nitrogen or of bacteria as such, were fully aware that the growing of legumes increased soil fertility and definitely practiced this as a part of their fertilizer policy.

Remembering the vegetable origin of coal it is evident that we are ultimately indebted to bacteria for even the nitrogen we recover in the form of ammonium sulphate from the destructive distillation of coal in our by-product coke ovens and city gas works.

We are not quite so sure about the great Chilean deposits of sodium nitrate, but an ultimate bacterial origin for even these seems at least as probable as any other yet suggested.

These nitrate fields of Chile, from which the first shipments were made about 1830, have long been the world's chief source of nitrogen both for commercial fertilizers and for explosives. Next in importance has come the sulphate of ammonia recovered from the distillation of coal as already referred to.

Up to a decade before the World War practically all the other nitrogen used in fertilizers came from animal or vegetable wastes, such as stable manure, slaughter house tankage, fish scrap, guano, cotton seed meal and the like.

But in 1902 a new era dawned in man's control of this very important department of material resources. In that year Bradley and Lovejoy, two American chemists, set up at Niagara Falls the first little apparatus ever definitely built to artificially fix atmospheric nitrogen for commercial purposes. It was based on the principle that when a powerful electric discharge or arc, as we call it, takes place in air some of the oxygen and nitrogen which were previously only mixed but not chemically combined, become in the intense heat of the arc chemically combined, and if their recooling is quick enough will remain combined. These oxides of nitrogen can then be absorbed in water to form nitric acid and, neutralized with lime, soda or potash, to form the corresponding nitrates, all of which when properly introduced into the soil are excellent fertilizers.

In every lightning flash there is undoubtedly some nitrogen fixed in this way and washed down out of the air to the soil by the rain. This process, of course, antedates even the bacteria and may have furnished some of the necessary compounds out of which the first bacteria arose, but to-day it supplies a negligible amount in comparison with that being constantly fixed by these organisms.

It is interesting and instructive to note that exactly this same electrical method was used and thoroughly described, including the chemical reactions involved by Cavendish in England, 150 years before, in his classic work on the composition of air, but its commercial application had to await the development of our modern hydroelectric industry to bring the cost of the process within the range of economic interest. Even the Niagara plant did not prove commercially successful, but the next year experiments were begun in Norway with even cheaper electric power and improved equip-

ment, and in 1905 the first commercially successful plant began operations there and is still running.

This process, however, consumes such enormous amounts of electric energy per pound of nitrogen fixed that it is only of interest in very special cases and as far as new installations are concerned may now be considered as having been completely superseded by other more modern and efficient processes.

Of these the one which followed immediately on the heels of the arc was the cyanamid process, which requires only about one quarter as much energy as the former. The first step in the cyanamid process and the one consuming most of the energy is the manufacture of calcium carbide in the usual way; *i.e.*, by melting coke and lime together in an electric furnace.

The resulting calcium carbide is then crushed to fine powder and treated at a red heat with pure nitrogen made from liquid air. The nitrogen combines directly with the calcium carbide to form calcium cyanamid. This can with certain restrictions be used directly as a fertilizer, but its possible application under American agricultural conditions is somewhat limited. It is more practical on a large scale to treat it with steam and alkali to form ammonia, or with weak acid solutions to form urea, both of which can find practically unlimited use as fertilizers if produced cheaply enough.

The cyanamid process reached the height of its success at the time of the World War, and is now being rapidly superseded by still more modern and more efficient processes.

It was known to the rest of the world even before the outbreak of the war that the Germans had perfected a new process which would probably supersede the cyanamid method for fertilizer and explosives purposes, as its power requirements were only about a quarter of those of the cyanamid, but nowhere outside of Germany was there sufficient detailed knowledge of it to permit the erection of large plants on this principle with any confidence of immediate successful operation. Yet the urge of war necessity made immediate action imperative. The great cyanamid plant at Muscle Shoals is one of the results. The $50,000,000 water power project there in connection with this, which will not be completed and ready for operation until next August, is, of course, a permanent, thoroughly useful and up-to-date asset, but the $70,000,000 cyanamid plant which was completed and tested out just at the close of the war was built frankly as a war emergency with full realization of how fast the industry was advancing and the consequent likelihood of this plant rapidly becoming obsolete.

Since the termination of the war we have learned much about the new German or Haber process for the direct synthesis of ammonia from its elements hydrogen and nitrogen, and the more we

learn of it both from others and through our own experiments, the more obvious does it become that it must inevitably supersede the cyanamid process for fertilizer and explosives.

At Muscle Shoals during the war the government also spent some $12,000,000 in the erection of a Haber type plant estimated at one fifth the capacity of the huge cyanamid plant. This direct synthetic ammonia plant was frankly an experiment and as a matter of fact was never put into successful operation. Its electric power requirements are so small compared to the other processes that its close association with the water power development has no special significance. The economic affiliations of this process are more naturally with coal mining and coke ovens, since the chief raw material it consumes would be either coke or coke oven gas, depending on which of two alternative procedures was used in preparing its hydrogen supply, which is the largest single factor of cost in the operation.

Briefly and very generally stated, the process itself consists in compressing a mixture of one part by volume of pure nitrogen and three parts by volume of pure hydrogen to a very high pressure, and then passing this mixture at a dull red heat through what is called a catalyst. The catalyst is a granular mass of specially prepared metallic iron containing small percentages of such substances as potassium aluminate called promoters. The preparation and protection from injury, both chemical or thermal, of this catalyst is one of the very delicate details of the process, and has required a great deal of research, as have also the engineering features of the process, involving as they do the handling of large volumes of gases through complicated operations at high pressures and temperatures.

But chemical engineering has already surmounted these difficulties and it is estimated that this year will see some 44 per cent. of the world's supply of inorganic nitrogen produced by atmospheric fixation as aginst 10 per cent. immediately before the war. Furthermore while this 10 per cent. was made almost wholly by the arc and cyanamid processes, nearly 70 per cent. of this year's fixation will be through the direct synthesis of ammonia.

THE CHEMICAL—ALCOHOL

By Dr. H. E. HOWE

WASHINGTON, D. C.

"HAVE you seen Al? Al who? Alcohol. Kerosene him last night, gasoline up against a lamppost and took a naphtha. He hasn't benzene since."

But the question is altogether too general. You must indicate which one of the many alcohols you mean. The chemist knows a large family of them, each with its own personality and special occupation. In composition they are somewhat similar, all being made from carbon, hydrogen and oxygen, but the proportions of these constituents differ and the arrangement of the atoms in the molecule makes all the difference in the world both as to characteristics and the use of the alcohols.

To the non-chemist alcohol always means grain or ethyl alcohol, and if he is a bit careless he may include wood or methyl alcohol under the same general name. This practice has led to the adoption by scientists and the trade of the word "methanol" for methyl or wood alcohol, to prevent the uninformed from confusing these two principal alcohols of commerce. Butyl and propyl alcohols are growing in industrial importance, but are less likely to be misused as a beverage.

By far the greatest production is of the ethyl or grain variety, for which waste molasses of sugar refineries, corn and in Germany potatoes are the principal raw materials. The conversion of starches to sugars and of sugars to alcohol involves technical processes requiring careful scientific supervision, while the distillation of the weak solutions of the alcohol thus formed to yield the alcohol of commerce is an engineering feat.

The general public may not be familiar with alcohol as a chemical, but nevertheless its use as such dwarfs into insignificance any other application of this material. In making solutions of substances as a step in manufacture, alcohol occupies a place of importance second only to water. There are a host of substances that can not be dissolved without it, including such familiar things as vanilla extract, a long list of shellacs and varnishes, the solutions of essential oils which we know as perfumes and many of the tinctures and extracts of medicine and pharmacy, where it is also used to dilute medicinal preparations and to preserve some of the active principles employed in medicine. In the manufacture of liquid soaps, in the preparation of shoe blacking and dressings, non-corrosive soldering fluxes, inks and disinfectants, in the silvering of mirrors and in making cleaning solutions, the chemical, alcohol, finds employment. Because some things will dissolve in alcohol and others will be thrown out of solution in the presence of alcohol, it is an important reagent in many purification processes, its presence or absence enabling some separations to be made with precision. Alcohol is so necessary in the dye industry that its low price in Germany was one of the important factors in the establishment and early development of the synthetic organic chemical industry in that country, as opposed to Great Britain where the first coal-tar color was dis-

covered but where a heavy tax on alcohol interfered with the development of that industry.

To enumerate all the uses of alcohol as a solvent would require the entire time at our disposal, for the list for which the government has prescribed special formulas of denatured alcohol and for the use of which permits are issued covers some five or six pages of closely printed matter. Among the uses of alcohol, however, are the following: artificial flowers and feathers, brushes, bronze powders, confectioner's colors, dental alloys, embalming fluids, enamels, fertilizers, incandescent lamp filaments, fireworks, gas mantles, hats, imitation ivory, japans, jewelry, mucilage, non-shatterable glass, lubricants, photographic engraving, photographic films, paper, refining precious metals, shampoo liquids, shoe polish, solidified alcohol for fuel, stencil paper, transparent paper, trinitrotoluol, celluloid and pyralin, synthetic camphor, furniture polish, smelling salts, imitation rubber, certified food colors, liniments and lotions for external use only, tincture of iodine, tooth paste, dentifrices and barbers' supplies.

The chemical, alcohol, may also be classed as a raw material in chemical processes. It is used to produce chloroform, iodoform, acetic acid, vinegar, ether, ethylene and the whole family of ethyl compounds which are used in turn for the production of artificial leather, varnish removers and a variety of commercial chemical compounds. For example, one of the largest manufacturers of automobiles is the largest user of ethyl acetate for the production of his artificial leather, which could not be made without ethyl or grain alcohol.

One of the greatest single uses of denatured alcohol is as an antifreeze solution for automobile radiators. A mixture of alcohol and water freezes at a lower point than the water alone, the proportion of alcohol determining how low a temperature can be withstood. An interesting chart has recently been prepared, showing the number of private passenger cars, motor trucks and cars for hire in the various states. The number of months of freezing weather in each state has been determined from the weather bureau records and from this information the number of gallons of alcohol required to operate these cars has been estimated. The total is slightly more than 28,000,000 gallons.

Alcohol bears another important relation to our transportation problem, namely, as a supplementary fuel ideally suited for use with gasoline. Alcohol possesses properties which enable it to act as an antiknock compound, giving something of the benefits which characterize tetraethyl lead, so widely discussed of late. Further, its use tends so to promote combustion as to keep the cylinders clean, and while its use alone does not give the mileage obtained

with gasoline with present-day engines, motors can be designed to employ alcohol economically.

Early experiments with alcohol in gasoline were not satisfactory because the commercial alcohol contained enough water to prevent proper mixing with the motor fuel, and materials added to insure this mixing led to corrosion troubles. Through scientific research a commercial method has been perfected for producing alcohol free from moisture. This alcohol, known as anhydrous or absolute alcohol, mixes in all proportions with gasoline and thus removes the former difficulties.

From a motor fuel standpoint alcohol has the unique distinction of annual production, a point which should interest farmers who may soon find it profitable to develop and grow crops as raw material for alcohol motor fuel production. This has been the case in Germany where a potato containing too much starch to make it attractive as human food has proved a commercial success for alcohol production. In Central and South American countries large quantities of alcohol are made from molasses from sugar factories and, mixed with ether made from this alcohol, used to drive motors of various kinds, including those on plantation railways as well as business and other cars.

In recent years artificial silk has become an important item of commerce, and the industry has shown phenomenal growth. Some of the finest varieties of artificial silk are those involving a solution of a cellulose compound in alcohol and ether, though of course none of this solvent can be found in the final product. A single artificial silk mill in this country is now using in excess of 2,000,000 gallons of ethyl alcohol per year.

In medicine and in scientific research alcohol finds a multiplicity of uses. Much that has been accomplished in the study of bacteria, in the study of tissues and body cells and in the development of methods for identifying and later overcoming diseases, would have been impossible without the use of this chemical compound. It is used in biological staining, in the gradual removal of water from material for study under the microscope and for a list of practical applications which necessitate an adequate supply of pure alcohol in every dispensary and hospital.

The extended current reference to methanol in the newspapers is due to the successful production of this solvent within the last year from two gases, carbon monoxide and hydrogen, by a process similar to that used for the fixation of atmospheric nitrogen. This artificial or synthetic methanol is reported to be made much more cheaply than the natural product obtained by the distillation of hard woods. The producers of methanol in America have devoted more attention to increasing yields and purification of product than to research on new methods for the manufacture of methanol.

Abroad, lacking natural resources, emphasis has been placed on the synthetic production of this liquid. It affords an excellent example of how necessary it has become for industries generally to apply chemistry to their manufacturing processes and continually to conduct research that they may know as much as any one regarding their subject. Further, it is an interesting example of how science frequently comes to our aid in supplementing materials heretofore derived solely from natural resources that are now fast disappearing.

It is unfortunate that the press has questioned the poisonous character of the new methanol. There is nothing to justify the impression that it may be less poisonous than any other pure methanol. Physiological chemists tell us that whereas ethyl or grain alcohol is burned to carbon dioxide and water in the human body, methanol is not only difficult to burn completely but the products of its combustion include formic acid, which has a fatal effect on the optic nerve, causing blindness, and frequently causes the death of its victim. Rather than question the toxicity of synthetic methanol, its danger should be emphasized. A service can be rendered by sounding a special warning, for pure methanol is more difficult for the layman to detect, as it does not have the characteristic odor which usually is sufficient to frighten off a drinker.

It will be clear that the current impression of alcohol does alcohol the chemical a gross injustice. Scientists and the industries are interested in having the public appreciate something of the utility of alcohol, in stressing which it should be pointed out that a great deal of time and money have been spent in an effort to find a satisfactory and useful substitute—so far without success. Its proper development under impartial enforcement of existing laws will do much to acquaint the public with its proper place in science and the arts.

THE THUNDERSTORM

By Dr. W. J. HUMPHREYS

U. S. WEATHER BUREAU

WHEN the weather is hot and sultry, and has been for two or three days, the blue sea of the sky becomes dotted here and there with mountainous islands of cloud, cumuli or summer cumuli, as we call them, snow-white on the sunlit sides and blue-gray over the shaded portions. After several hours of sunshine, and especially about mid-afternoon, one of these great woolpack masses, already of large size, grows faster than its neighbors and quickly raises its tumultuous top miles above the surface of the earth. Presently rain begins to fall from this great cloud. Then it and all the ele-

ments are rudely changed. Calm gives way to turbulent blast, and the erstwhile quiet and beautiful summer cloud becomes a dark and angry tempest.

Shortly after the rain begins the top of the towering cumulus reaches its greatest height and there often spreads out or is pulled out by swifter upper winds into a thinnish and more or less fibrous sheet that may extend far ahead of the storm itself. In this case, then, after the storm is fully developed and on its way the first evidence one has of its coming is the covering of the sky with a fibrous haze, whose tangled threads soon thicken to a high white canopy and that in turn to denser and darker cloud. In a little while now, if not already, one sees in the direction from which the storm is approaching, somber, mountainous forms, the cumulo-nimbus of the meteorologist, the tops of which may be hidden by the general cloud sheet. Already the sun is obscured and the excessive heat tempered a little by the gracious shade. But an oppressive stillness prevails —a solemn hush as before an unknown but impending doom. Presently distant lightning is seen near the denser portions of the cloud, and before long the faint rumble of thunder is heard.

As the storm draws nearer a grayish surf-like billow, the storm collar, passes overhead. A gentle breeze is felt blowing towards the oncoming tempest. A curious roll of scud whirls over and over along the forward base of the storm cloud just in front of the gray-blue curtain of falling rain. In a few minutes the warm inflowing breeze is replaced by a relatively cool outblowing gale, bending trees and driving dust and leaves before it. The lightning flies. The thunder roars. Big drops of rain fall, mingled perhaps with hail. Immediately the rain comes down in driving sheets, but in a few minutes the worst is over. In half an hour, more or less, the windward clouds grow thinner, the lightning becomes fainter and the thunder fades away. Soon the rain ceases entirely and the sun shines in a clean, clear atmosphere. All nature is refreshed and only a vanishing storm may be seen through the arc of promise—the gorgeous multicolored bridge of the gods.

Such is the glory and the grandeur of the thunderstorm. But how, we ask in our prosaic and inquisitive moods, is it produced? What causes it? Well, first of all, the air has to be humid. Rain can not be gotten from dry air any more than blood can be gotten from the proverbial turnip. Next, the water must be gotten out of this air in the form of rain, and that is done by forcing it up to high levels. This occurs whenever the lower layers are sufficiently warmer than those at considerable heights, a condition that can occur in more ways than one. The most obvious way, however, and the most frequent, especially in the warmer portions of the world, is by heating the surface of the earth through exposure to sunshine. This is why thunderstorms are more frequent in tropical regions

than elsewhere; more frequent in summer than winter and in afternoons than forenoons. The heated soil heats, in turn, the air next to it, both by contact and by radiation. This air, like all gases, expands strongly as its temperature is raised and thereby becomes lighter, volume for volume, than the air above it, not so warmed, would be if at the same pressure. Hence any little disturbance, such as the slightest breeze, starts these two masses of air, the warmer and the colder—the under and the upper—exchanging places. As this process, a sort of forced stirring, goes on, the atmosphere is gotten into such a state in respect to its change of temperature with height that a small increase of temperature at the surface causes the air thus warmed to be pushed up—to ascend, we usually say— to a considerable height.

As the humid surface air rises, it expands, because as it rises the load on it, that is, the weight of the air still above it is continuously decreasing. But all the time this load is considerable, roughly eight to fourteen pounds per square inch, and the expansion against it requires a correspondingly large amount of work. This work in turn is done at the expense of the heat of the expanding air, hence it must get colder, and it does so at the rate of about 1° F. for each 187 feet increase in height. Now, the amount of water vapor that can exist in a given volume, such as a cubic foot, rapidly decreases with decrease of temperature. Hence the rising humid air soon cools by expansion to what we call its dew point, or saturation temperature, that is, the temperature below which the water present can not all exist as invisible vapor. As soon, then, as the rising air, or, to speak accurately, the pushed-up air, has cooled below its dew point, cloud begins to form, and the higher this ascent the bigger and higher the cloud.

Right here another thing happens that is vitally important to the formation of the cumulus or woolpack cloud and the genesis of the thunderstorm. As the water vapor condenses into liquid there is set free the heat of vaporization, which prevents the rising air from cooling as much for a given ascent as it otherwise would. All the inner portion of the cumulus cloud therefore is warmer than the air at the same level on the outside. In short, the cumulus cloud makes of itself a sort of a heated chimney, up which air rushes so rapidly and in such volumes as to form the great outwelling, cauliflower thunderheads.

Presently rain forms in the towering cloud and cools the lower air through which it falls, largely by evaporation. This cooled air in turn, increasing in density, as it is chilled, drops to lower and lower levels and soon quite to the earth, where it rushes forward as the dust-raising gale that just precedes the rain. The outrushing cooler air underruns and buoys up the warm humid air in front of it—starts upward this feeder and maintaining support of the storm.

The cooler air that comes down with the rain rushes forward on the ground and stays down. The warmer air that is pushed up enters the forward portion of the storm, furnishes the rain and stays up.

Now, the rapid uprush of the warm air from which the cloud and rain are condensed causes another thing of interest, namely, the production of hail, and it comes about this way: Since no raindrop can fall through still air faster than about twenty-five feet per second, nor the smaller ones nearly that fast, it is clear that the uprushing air within the thunderstorm cloud carries much rain to great heights where, in many cases, some of it is frozen. But the rising air is fitful and puffy, so that the frozen drops fall back again to lower levels where they pick up a coating of water. Many of them fall on down and are melted on the way. Others, however, are caught in another rising blast and again hurled back to the freezing levels where a further coating is gathered. In this way, many of the stones are carried back and forth between realm of snow and region of rain, until, with shell after shell of clear ice and opal snow, they have grown so large and heavy that the uprushing air no longer can support them, and they fall to the earth as hailstones; generally no larger than ordinary marbles, but on rare occasions as big as baseballs and decidedly dangerous. The torrential precipitation of the thunderstom and its rain gushes are caused by the rapid and fitful uprush of the sustaining humid air.

There still is another feature of the thunderstorm, the very thing that makes it a thunderstorm, the lightning, that is caused by the uprush of air in the midst of the cumulus cloud. As the raindrops are driven up and whirled about by the convectional winds within the cloud they over and over are united into larger drops and again broken asunder, while with every rupture tiny droplets are torn off and carried on to still higher levels. But this is not all. As Simpson, the present director of the British Meteorological Office, has demonstrated, the breaking or rupturing of the drops is also an electrifying process. The larger drops become in this way positively charged and the spray negatively charged. Furthermore, the larger drops with their positive charges accumulate, because they are relatively heavy, in the lower portion of the cloud, while the negatively charged spray, because it is lighter, is blown to the upper portion. As these charges grow, the tendency to discharge—for the opposite charges to unite—increases until at last the spark or lightning, as we call it, passes; generally between the upper and lower levels of the same cloud, and less frequently to the earth.

The lightning usually lasts only a small fraction of a second, and often is flickering, owing to a series of separate discharges following each other in quick succession along the same path.

The duration of the flow of the current is very short, but its volume, while it lasts, is amazingly great, even tens of thousands of amperes. Its path through the air often is several miles long, devious and frequently branched at the sharper turns, but very slender. We do not know how slender, but there is reason to believe that even the most violent discharges may be no thicker than a lead pencil.

The discharge suddenly heats the air through which it passes to an unknown but very high temperature, and also tremendously ionizes it, that is, in a sense, smashes to pieces its very atoms. Thus a violent explosion, or outblow of the air, is produced all along the path of the discharge. It is this explosion that starts the sound waves we call thunder.

A great deal more might of course be said about the thunderstorm and its phenomena, for the subject is a big, interesting and important one; but this is enough, perhaps, to assure us it was no idle boast of the giant cumulus when it averred:

> I wield the flail of the lashing hail,
> And whiten the green plains under,
> And then again I dissolve it in rain,
> And laugh as I pass in thunder.

INSECT SOCIOLOGY

By Dr. VERNON KELLOGG
THE NATIONAL RESEARCH COUNCIL

THE human sluggard is told to go to the ant to learn industry. The human sociologist might be told to go to the ant to learn sociology, for the ants have carried one form of social life to a degree not yet nearly approached by any group of human beings. This is that form called communism. Perhaps we can learn from the ants whether we ever want to go as far as they have in the way of communism.

Ants are insects, but not all insects live social or communal lives. Most of them live solitary and independently as individuals, although they may be crowded together in enormous numbers. Some entomologists attempted to estimate the number of plant lice living on one little cherry tree. He made it, in round figures, about 12,000,000. But these plant lice were not social; they were just so many individuals crowded together but having no special relations to each other. Some of *us* are inclined to live that way.

There is a beautiful large red-brown butterfly, called the monarch, which is spread all over this country. These butterflies live most of their lives as quite independent individuals, having nothing

to do with each other except at mating time. But they show a certain beginning social life, for sometimes tens of thousands of them come together, because of some gregarious instinct, although for what purpose we do not know. I have seen such gatherings in California where, in a few pine trees on the shore of Monterey Bay, there would be thousands of these butterflies, clinging to the branches and to each other, so as to form beautiful, living festoons, hanging from the trees.

There are certain small mining bees, each female of which makes a little nest burrow in a claybank in which it lays an egg and places a store of food for the young which is to hatch from this egg. But a few kinds of these bees have developed the interesting habit of having several mother bees combine to dig a common main burrow, off from which each mother makes a private short side burrow for her own egg and food; a sort of first step toward apartment house social life.

Then come the bumblebees, all the species of which live in family communities in rough nests underground, with three kinds of individuals or castes making up the family; a queen, which is the mother of the whole community, some males, which are drones, doing no work, and a large number of workers which are females, incapable, however, of laying eggs. The community is started by a queen or egg-laying female which has passed the winter in solitary hiding under a stone or in a crevice in the ground, and which comes out in the spring, hunts a place for a nest, gathers a little mass of flower pollen and nectar and lays a few eggs on it, from which hatch only workers. These workers enlarge the nest and bring more food, while the queen stays at home and lays more eggs. This process is repeated several times, until late in the summer a brood is hatched in which are males and new queens as well as workers. Then the males and new queens leave the nest, and the workers begin to die. Later the males die, and only a few queens are left to go into hiding for the winter and come out in the next spring to found new families.

The social wasps, such as the yellow jackets and hornets, have the same kind of a social life history as the bumblebees, only their nests are usually made above ground of wood-pulp paper fastened under eaves or attached to the branch of a tree. But both bumblebee and social wasp communities break down each year.

Not so with the honey-bees. Their communities go on continuously, only part of the workers dying in the fall, and enough pollen and nectar being stored up in the autumn to provide the community with plenty of food through the winter. The queen may live for four or five years, new queens being produced occasionally,

each to start a new community by going out of the hive with a swarm of workers, thus providing the beekeeper with the nucleus for a new hive.

In a honey-bee community the different kinds of necessary work, such as food-gathering, wax-making, cell-building, nursing the young bees, cleaning and ventilating and guarding the hive, etc., are done by different groups of workers. There is a division of labor among them, which is exactly what forms the basis of human social life.

When we come to the ants we find many varying degrees of communism for, unlike the bees and wasps, many kinds of which live strictly solitary or independent lives, all the different kinds of ants—and we know more than 3,000 of them—maintain some form of communal life. The communities of some are small, with only a few dozens of individuals in them, while some are very large, with hundreds of thousands of members. There are often, also, several kinds of individuals among these members, not only queens, drones and workers, as with the bees and wasps, but also soldiers and different sizes of workers. And each kind has its own particular function to perform in the community.

Ants, like human beings, have different ways of getting a living. Some are hunters, capturing and killing other insects; some are agricultural, collecting and storing seeds for food; some are predatory robbers, carrying off the stored food of others. Some have adopted a kind of dairying habit, taking care of herds of plant-lice, the "ant-cattle," from which they get honey-dew, which has been called the national dish of the ants. Some are slave-makers, depending on slave ants to take care of their young and do all the work of the community. Two different kinds may also live together as messmates; or as hosts and parasites.

Now with all the ants and with those kinds of bees and wasps which have adopted a communal life, there is an entire giving up of the life of the individual for the life of the community. Each worker ant or bee or wasp works not for itself but for the community. The worker collects food not for itself but for everybody. It has no children of its own; but it helps take care of the children of the community, which are all produced by the queens. Biologically, the communal insects are very successful. Their communities thrive; their species persist and increase. They live in all the lands of the earth except in extreme arctic and antarctic regions, and on the summits of lofty mountains, and their numbers probably exceed those of all other insects. They have been called the most successful of insect kinds. But are they happy? Nobody knows.

THE CONSTRUCTION OF MEASURING INSTRUMENTS IN THE FIELD OF EDUCATION

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THE development of a science of education is no isolated phenomenon. It has a history as well as a background. In my opinion the significance of present-day achievements in the development of educational measuring instruments, and the correct interpretation to be placed upon the period of educational experimentation through which we are now passing, are both to be derived from a consideration of what has taken place in other sciences.

I am going to attempt to present three distinct, but related, sets of ideas. First, with the aid of historical analogies, I shall endeavor to interpret the present status of education as a science; second, I shall review significant aspects of the existing techniques of test and scale construction; and, third, I shall discuss certain aspects of the difficulties met in making use of measurement in the field of education. In covering so wide a range of ideas I shall be in danger of making statements too broad, generalizations too far-reaching. For all such lapses from scientific precision I apologize in advance; my purpose is to sketch in broad outlines a picture that too much elaboration of detail would mar.

I. THE PRESENT STATUS OF EDUCATION AS A SCIENCE

If we review the story of man's progress in the control of natural forces, we find that through many centuries the rate of increase in control was very slow, indeed. However, there came a time when the technique of inductive experimentation was clearly formulated and ably demonstrated. Ever since that day all who have desired to do so have been able to pursue the search for truth in a manner that is certain to secure substantial rewards.

There is no need for me to remind you of what happened; of how the new method spread from one field to another. In each field to which it has been applied it has invariably transformed the existing concepts and explanations from a speculative to an experimental basis. The diagram presents the essential elements of the evolution of science in a manner which will enable you to

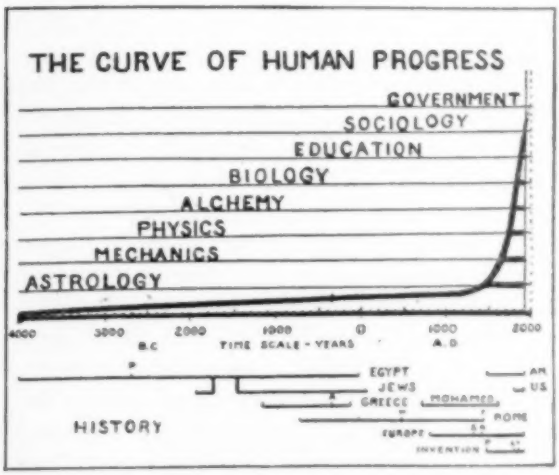


FIG. 1. The curve in the figure is drawn to represent the rate of growth of human control over the forces of nature during the last six thousand years of human history. The period of rapid growth began with the clear formulative and effective use of the inductive method about 1200 A. D. The use of the method in connection with the method of logical deduction developed during the previous centuries has spread from one field of activity to another. For comparison the duration of various nations and countries is shown below. P = building of pyramids, A = Aristotle, W. E. fall of Roman empire in West and East, S = scholasticism, R = renaissance, P = printing, S = steam engine, T = telephone.

get easily the first point I wish to make, that present-day attempts to study educational problems scientifically are but the inevitable outcomes of the spread of scientific methods from the first fields of inquiry in which they were developed. Man has at last begun to apply to himself that technique of investigation which has proved so effective in all other fields. He has at last begun to use on himself the one means by which it is possible to differentiate between ideas which are merely products of imagination and those which are in accord with nature's immutable laws.

It is reasonable to suppose, is it not, that the course of development of a science of education will closely parallel the development of sciences in other fields. There are regular cycles in such development. For instance, the primitive stage is what may be called "general" observation, such as is possible with the unaided eye or with simple counting or measuring. A "common-sense" explanation soon follows: an explanation, however, which usually contains many imaginative and mystical elements. If we use the field of astronomy for an illustration, the common-sense explana-

tion is that the sun, moon and stars revolve around the earth, and the imaginative and mystical elements are all the weird beliefs and practices associated with that oldest of the pseudo-sciences, astrology. Any theory, however, has this virtue; it stimulates further observation. Eventually discrepancies and difficulties are discovered which in time give rise to new concepts and to a rival theory. Then a conflict begins. In such a situation it is recognized that the truth of either theory can be established only by the aid of more complete and more precise data. Measuring instruments are invented, recourse is had to experimentation and a transition period ensues, characterized by a chaos of conflicting hypotheses and by the rapid accumulation of a rich fund of data. In the fulness of time, a man of genius arises, a new synthesis takes place, new generalizations are made, laws are formulated and order is restored. The invention of measuring instruments and a feverish period of experimentation under conflicting theories are the outward signs of a transition phase.

An interesting aspect of the process is the length of time it takes to change from the old to the new. Counting from the first publication of his ideas by Copernicus in 1529[1] to the publication of the Rudolphine Tables by Kepler in 1627 the period for astronomy was almost exactly a century. Even from the beginning of the construction of better instruments of observation by Tycho Brahe to the formulation of the great generalizations of Kepler was 33 years (1576–1609). The total time of the transition period from the announcement of the new theory by Copernicus to its complete proof by Newton through the formulation of the law of gravitation was a century and a half.

If we turn to another field the various phases of the process take approximately an equal interval of time. Thus, from the publication of Boyle's "Sceptical Chemist" in 1661, with its appeal to the balance and to experimentation, to the formulation of the atomic theory in 1804 was also approximately a century and a half. The first century of this period was devoted to the development of instruments and techniques of measurement. It ended with the development of the new concepts of elements, mixtures and compounds to replace the "fire, water, earth and air" of the ancients, but it required another full generation (34 years) of measurement, experimentation and discovery before the harmonizing generalization of the atomic theory was reached.

More pertinent to our interests to-night, perhaps, are the figures in regard to the development of instruments for measuring tem-

[1] This and the following dates are taken chiefly from Sedgwick and Tyler's "Short History of Science" and from the Encyclopedia Britannica.

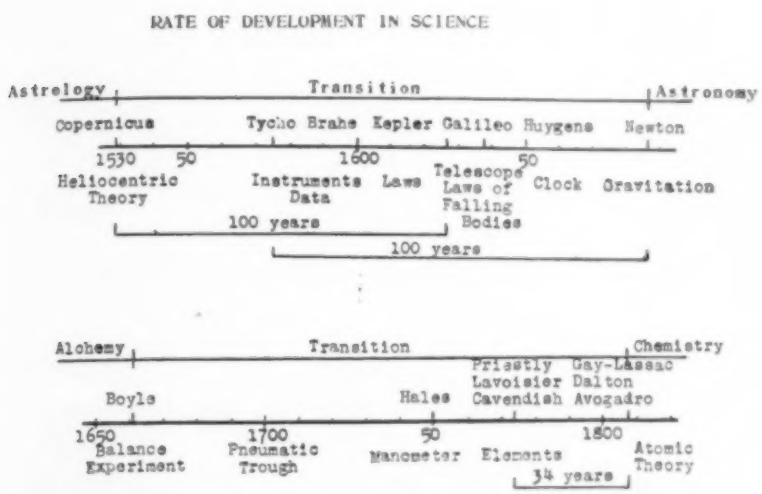


FIG. 2. The figure shows a time scale for two periods of transition, the first from astrology to astronomy, the second from alchemy to chemistry, each approximately 150 years. Men are given above the time scale and events below. These periods are characterized by the invention and perfection of measuring instruments and the rapid accumulation of data.

perature. Galileo gave the world a crude air thermometer in 1597, but it took more than a century (117 years) before the improvements that were gradually made culminated in Fahrenheit's mercury thermometer. This instrument, which was so satisfactory that it has continued in use until the present day, is of special interest to measurement men in education; for it is a scale without a true zero point, like most of the educational scales. Yet it has proved to be of very great service. In spite of its serviceableness, it is important to note that 63 years passed before Charles was able to announce the law for volume and temperature in gases. Yet Boyle as early as 1661 had determined the relation between pressure and volume in gases at constant temperature. The law of Charles made possible the concept of absolute temperature, but this generalization was not given to the world by Lord Kelvin (1862) until another 75 years had passed.

Instances such as these might be shown from many sciences. In general, it would seem that it has taken at least three generations (100 years) from the time a new master theory has been announced before measuring instruments have been invented and scientific experimentation begun; also it has taken on the average at least one and usually two generations after the invention of measuring instruments before important generalizations in the form of laws have begun to appear.

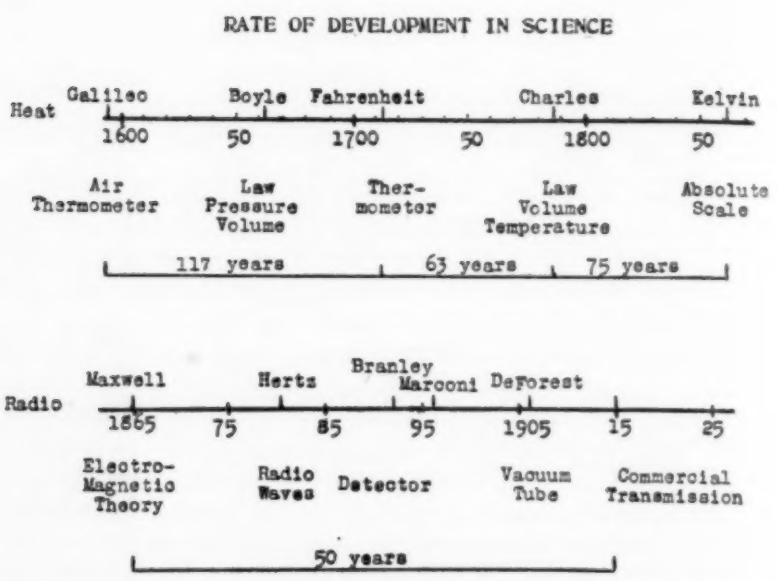


FIG. 3. The figure shows a time scale for the development and perfection of measuring instruments for heat and another for the important developments in radio. The plan of the figure is the same as that of Fig. 2.

Each new science inherits a growing mass of knowledge and technique, much of which it should be able to transfer to its own field, thus greatly shortening the period needed for its development. Also in our day the means of communication are so perfected that new discoveries are immediately made available the world around. This, too, should shorten the developmental period. On the other hand, it may be well to remember that the fields most susceptible of analysis were the first ones in which discoveries were made. Even in our own day, sixty years have passed since Maxwell announced his electromagnetic theory, but we have not yet reached the end of the period of resultant rapid growth.

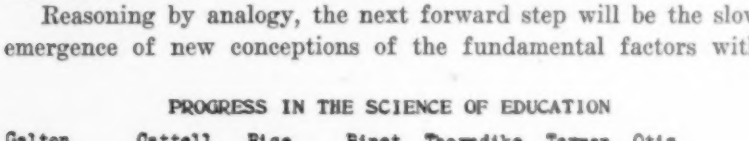
The science of education rests on the theory that the growth of man and the development of mind and spirit are natural phenomena, taking place in accordance with discoverable natural law. The conflicting theory, still held by many, is that the growth, thoughts and feelings of man are expressions of a spiritual entity and of forces which transcend natural law. It would seem that we are in the early stages of what has been termed previously a transition period, characterized by the multiplication of measuring devices and the accumulation of experimental data.

The end of the primitive period is placed by many at 1875, when Galton in England, Wundt in Germany and many others began to organize systematic, experimental study of human behavior. In this country Cattell in 1885 was giving psychological tests similar in purpose and content to some of the intelligence tests used to-day. In 1892 Rice was testing school systems on the comparative basis. In 1906 Binet (in France) developed individual intelligence testing; Stone in 1908 improved on Rice's work by standardizing the examination, but it was not until 1910 that the first true measuring instrument was published—the Thorndike Handwriting Scale.

From 1875 to 1910 is but thirty-five years, a relatively short period as such periods of development go. Other tests and techniques soon appeared. I, myself, developed units on the basis of objective criteria in 1910. Ayres (1912) made use of the variability of the distribution in scaling samples of handwriting. Buckingham (1913), Trabue (1916), and McCall (1921) introduced other applications and refinements. Terman in 1916 improved upon the work of Binet, and Otis in 1917 developed group intelligence testing. In recent years both educational and intelligence tests have been used literally by the million. To-day teachers everywhere are becoming accustomed to the impersonal, objective point of view, and experimentation of many types and kinds is rapidly yielding a large mass of conflicting and undigested data.

Reasoning by analogy, the next forward step will be the slow emergence of new conceptions of the fundamental factors with

PROGRESS IN THE SCIENCE OF EDUCATION



Year	Man	Contribution
1875	Galton	Experimental Study of Human Behavior
1885	Cattell	Psychological Testing
1892	Rice	Comparative Testing
1906	Binet	Individual Intelligence Tests
1908	Stone	Standardized Examination
1910	Thorndike	Development of Units on Basis of Judgments
1910	Courtis	Development of Units on Basis of Objective Criteria
1912	Ayres	Development of Unit on Basis of Distribution
1913	Buckingham	New Application of Scaling Procedure
1916	Trabue	New Application of Scaling Procedure
1916	Terman	Refinement of Individual Intelligence Testing
1917	Otis	Group Intelligence Tests
1921	McCall	Refinement of Units Derived from Distributions

FIG. 4. The development of education as a science is shown on a basis comparable with that of the two previous figures.

which education has to deal and the invention of methods of measuring their effects in terms of objective units. The new concepts are already dimly outlined, but it may be expected that the exact definition, precise measurement and generalization in the form of laws will require at least one and probably two generations from the time of the invention of the first measuring instruments. That is, the transition period is not likely to end much before 1975 (1910 + 65) but an important forward step in the development of new analytical procedures and the clarification of conceptual ideas should be achieved by 1945 (1910 + 35). Possibly one of the younger men in this audience is destined to be the genius who is to make this great contribution.

In this connection a quotation from a work published in 1569 by Petrus Ramus, a French mathematician and philosopher, may not be out of place. He expressed the hope that "some distinguished German philosopher would arise and found a new astronomy on careful observation by means of logic and mathematics, discarding all the notions of the ancients."

It seems to me that we who are interested in the science of education have reason to be proud of the progress already made. The conflicting theories have been clearly defined, instruments of measurement have been invented, and important data are accumulating rapidly. What we need to do now is to welcome each new idea, each new lead, and follow it experimentally until we have determined the worth of the contribution it has to make. Above all, we should feel under obligation to make the results of experimentation available to others. We can not tell from what stimulus the new ideas may come. The need of the hour is for originality, fertility of invention, new points of view, and, above all else, that true scientific spirit which welcomes all, but accepts nothing except on the basis of valid evidence. We must scrutinize every assumption, every technique and, more rigidly than ever before, follow only where the facts lead.

II. Significant Aspects of the Technique of Test and Scale Construction

In a brief address of this sort, I can not hope to give any adequate account of the methods by which tests and scales are made, but it should be possible to outline certain fundamental procedures which are essential to an understanding of the difficulties in which the science of education finds itself at the present time.

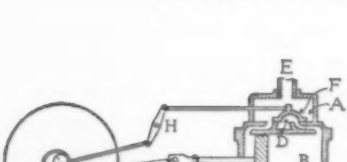
I have chosen four methods for discussion:

Method	*Product*
(1) The "stunt" or exercise method	Examinations
(2) The recognition of difference method	Product scales
(3) The variability unit method	Performance scales
(4) The objective specification method	Rate tests

The "stunt" or exercise method is that method of test construction in which one selects a number of items similar in nature in terms of some general category and involving a desirable mental activity.

GENERAL SCIENCE TEST

FIGURE 9



In this drawing of a steam engine:

a The fly wheel is marked by the letter .....
b The piston is marked by the letter .....
c The steam chest is marked by the letter .....
d The cylinder is marked by the letter .....
e The sliding valve is marked by the letter .....

FIGURE 17

a This diagram illustrates the giving off of..... *a*
by the leaves of plants.
b This process is called..... *b*
c The rate of this process in the living plant is partly controlled by the action of the.....found in the..... *c*
of leaves.

FIG. 5. Illustration of test composed of carefully selected items each of which is really a small test in itself so that the score as a whole is merely an index of a complex of abilities instead of an expression of magnitude of a single unitary quantity.

I have chosen as an illustration an excellently prepared test of knowledge in which the defined category is general science. A test of this type has many uses and is of great service to many different types of educational workers. Yet measurements with such a test differ fundamentally from the type of measurements which are essential to the reduction of data to general laws. For instance, each item differs in content from each other item and the resulting score is only an index of general efficiency in the field covered by the test. The point I want to make is that such tests—and very many of our tests are of this character—are not true measuring instruments in the sense that they do not measure a single factor in terms of unit amounts of that factor. A score of twenty-five correct

answers in this test does not mean twenty-five units of anything. It is merely an index of the amount of an unanalyzed complex. In reality each separate item is a test in itself, but a test whose value in terms of a single unitary factor is unknown. We standardize scores from such tests in terms of grades or ages, we use them to measure rates of growth, the behavior of pupils, the relative efficiency of different methods of teaching; but all such measurements fall short of being true measurements in two particulars:

(1) The quantity measured is not unitary in character, and

(2) Any unit of amount is not equal to any other unit.

The physicist who measures length measures a magnitude of single specific characters, and any one inch of length is exactly replaceable by any other. The exercise method of test construction, in proportion to the care and attention given to the selection of content, yields valuable instruments for more precise description than is possible without them. But all measurements made with such tests are in terms of magnitudes which can not be used in the determination of law. The factors measured are overlapping complexes, and the magnitudes are not additive.

The Thorndike Handwriting Scale,[2] however, is a true measuring instrument, although by no means a perfect one. The thing measured is a simple unitary quality, "merit" in handwriting, and each unit is equal to each other unit, within the limits of the definition of unit adopted. The Thorndike scale is an educational "ruler" for measuring merit in handwriting. The merit of any new sample is determined by comparing it directly with the merit of the samples of known value which compose the scale.

In determining the value of the samples in the scale, use is made of the equal difference theorem formulated by Fullerton and Cattell.[3] The first step is to define a unit difference in merit. Two samples are taken as differing one unit in merit when, of a group of competent judges, 75 per cent. agree that one is better than the other. If a large number of samples ranging from poor to good are compared with each other by a sufficiently large group of judges, a series of samples may be selected each of which is recognized as better than the one below it by 75 per cent. of the judges. Thus in the figure "A" is one unit better than "B" and "B" is one unit better than "C," because in each case the difference is recognized by 75 per cent. of the judges. Samples A, B and C form a section of a scale, each element of which differs from the element below it by a unit amount. It only remains to determine how far the poorest

[2] *Teachers College Record*, March, 1910.

[3] "On the perception of small differences," University of Pennsylvania Press, Philadelphia, 1892.

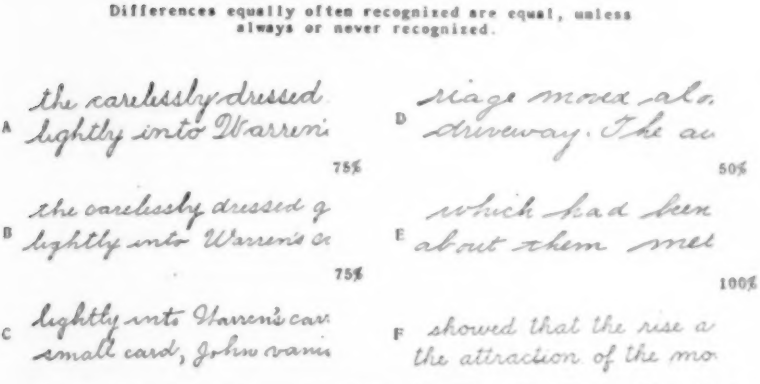


FIG. 6. Portions of samples from the Thorndike Handwriting Scale. Sample A is as much better in merit than B as B is than C, because the differences are equally often recognized. (Each difference is recognized by 75 per cent. of the judges.) Samples D and E are equal because the judgments divide 50–50. In the case of E and F, however, while F is better than E, it is impossible to tell how many units better because the difference exceeds the limits of doubtful discrimination.

sample is above zero writing, or writing of no merit, to fix the value of each element of the scale.

If two samples of equal merit are compared (as D and E) 50 per cent. of the judges will say one is better and 50 per cent. that the other is better. On the other hand, if the differences between the two samples exceed the limit of doubtful discrimination, 100 per cent. of the judges will recognize the difference, no matter how much beyond the critical amount the difference in merit may be. That is, between the limits listed in the theorem "always noticed" (100 per cent.) and "never noticed" (50 per cent.), it is possible to change percentages of "better than" judgments into units of amount. In the figure four diagrams are shown. The first (50–50 per cent.) represents the judgment results when the samples are equal, the second (67–33 per cent.) when the samples differ by half a unit, the third (75–25 per cent.) when the difference is one unit and the fourth (91–9 per cent.) when the difference is two units. Notice that a normal surface of frequency is assumed and the 75–25 distance from the mean along the base line is used as a measuring rod. The percentages of the normal surface of frequency corresponding to each unit, or fraction of a unit, along the base line are readily computed.

The actual process of selecting and evaluating samples followed by Professor Thorndike and others who have constructed scales by

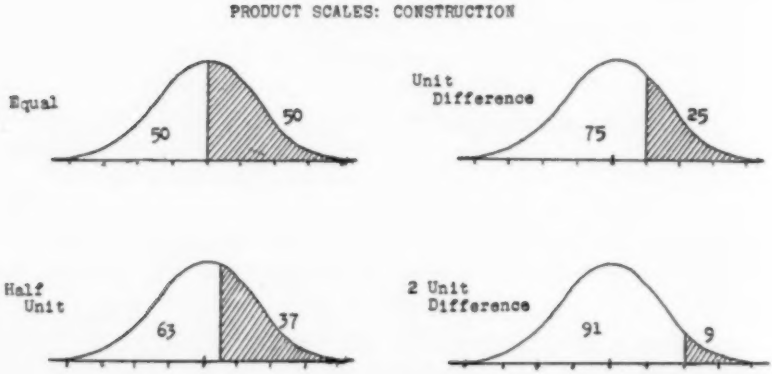


FIG. 7. Illustrations of the relation between the percentages of "better than" judgments and the division of the base line into units. White = "better than" judgments; shaded = "worse than" judgments for one sample. The distance from the mean to the shaded portion in the figure representing 75–25 is taken as the unit.

this technique was much more complex than that described, but enough has been said to indicate a general process of evaluation which yields measures of amount in terms of equal units. The resulting scale thus satisfies the two criteria given for a true scale, the unitary character of the quantity measured and equality of units of amount.

However, there is experimental evidence that while the units are equal in the sense of being equally often recognized, they differ in their absolute values.[4] This is in accord with the Weber-Fechner law as quoted by James,[5] that sensations are proportional to the logarithms of the stimuli which cause them. Equal difference units, being based on sensations, are units of varying absolute magnitude. In the figure equal difference units are shown along the base line, while the perpendiculars represent the corresponding absolute magnitude, in terms of the Weber-Fechner law, of the sensations necessary to produce them. The difference between the curve and the base line shows graphically the difference between geometric and linear scales. It is not known whether the handwriting units follow an exact logarithmic law or not, but it is certain that the relation is of this general character. Consequently, one of the problems of measurement with such scales is to determine the exact relation which holds between such units and to use the mathematical procedures appropriate for units of varying absolute magnitude.

[4] Unpublished paper presented before Section Q at a previous meeting.
[5] "Psychology" (Briefer Course, 1905), page 22.

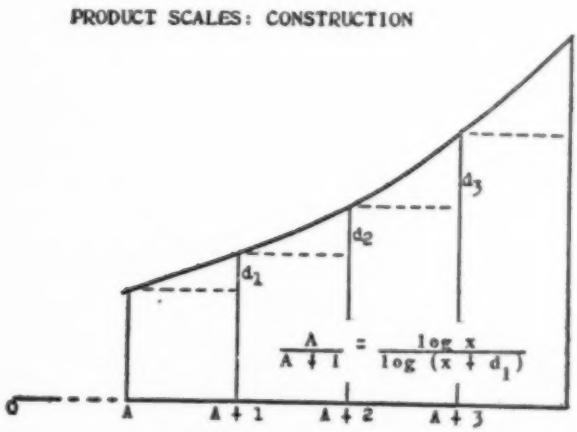


FIG. 8. Illustration of relation between equal judgment units, A to (A+1), (A+1) to (A+2), etc., (base line) and the corresponding true absolute values of the sensations upon which the judgments are based (perpendiculars) if judgment units follow the Weber-Fechner law.

A second problem is the determination of the best methods of locating the zero point, a problem too complex to be more than mentioned at this time.

A third problem has to do with the determination of the competency of the judges. It has been shown experimentally that the absolute magnitude of judgment units is a function of the degree of discrimination of the judges.[6]

These difficulties do not destroy the value of the scale as a measuring instrument, but they make it more difficult to correctly interpret the results secured. Nevertheless, it is now possible to measure the personal errors of those who use the scale, to determine easily the quality of any sample within 2 per cent., and to reduce this error any desired amount by giving sufficient time and care to the procedure followed in constructing and using such scales.

The second method of constructing true measuring instruments is the variability unit method. Fundamentally, it is an extension of the principles underlying the recognition of difference method. In this case, however, the units are not based on *recognition* of differences, but upon differences in performances caused by differences in difficulty. This is the reason tests so constructed are called performance scales.

For illustration I have chosen a few words in spelling from the spelling performance scale evaluated by Buckingham.

[6] "The effect of competency in judges upon the size of the unit in judgment scales," *School and Society*, Vol. XVIII, No. 446, July 14, 1923.

VARIABILITY UNIT METHOD

	Words	Percentage Failing	Percentile Value
1.	_____	0	0
2.	Only	11	30
3.	Forty	35	44
4.	Saucer	58	53
5.	Too	73	60
6.	_____	100	100

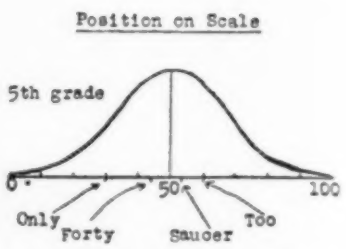


FIG. 9. Illustration of a performance scale in spelling and of the location of the elements of the scale on the base line of a hypothetical distribution by the "percentage failing" method.

The words "only," "forty," "saucer," "too," constitute a scale for the measurement of a simple unitary type of performance, spelling, because if difficulty in spelling is defined as that quality of a word which determines the frequency with which any homogeneous group of children misspell it, "too" is more difficult than "only." "Too" is misspelled by 73 per cent. of fifth grade children, while "only" is misspelled by but 11 per cent. of the same children.

The degree of difficulty of a word is determined by its position on the base line of a surface of frequency, distance from the mean being measured in terms of variability. That is, spelling ability is assumed to be distributed normally, and the mid-point of the distribution is taken as 50 units. If now the further assumptions are made that (1) the base of distribution is cut off at certain points (ordinarily at three times the sigma distance above and below the mean), that (2) a word so easy that no fifth grade child misses it has zero degree of difficulty, and that (3) a word so difficult that every fifth grade child misses it has 100 degrees of difficulty, zero being located at one end of the base line and 100 at the other, then points on the base line may be found corresponding to the percents of children missing various words. In one illustration, "only," missed by 11 per cent. of the children, falls at 30 degrees of difficulty and "too," missed by 73 per cent. of the children, has a difficulty value of 60. Thus "too" is twice as difficult for these fifth grade children to spell as "only" in terms of defined units.

It may be questioned whether the assumptions made are warranted or not. The answer is that at present we do not know. There is, of course, some evidence in support of each assumption, but there is other evidence which is in conflict with the first. Furthermore,

certain points have not yet been thoroughly investigated. Such scales are undoubtedly less perfect than they will ultimately be, but that is not the point. The important matter for the present discussion is that the variability unit method provides for evaluating difficulty of performance in a constant manner. Measurement with such performance scales enables the scientist in education to gather objective data from which he can not only describe educational phenomena more precisely than before, but also test the validity of the assumptions on which the construction of the measuring instruments is based. Such experimentation inevitably leads to the improvement of the technique of construction.

There are three important problems which must be solved before performance scales can be perfected. If some other means could be found for determining the difficulty of spelling performance, it would be possible to check one series of values against the other. Objective determination of difficulty is greatly to be desired, but little progress has been made in this direction. On the other hand, certain difficulties, caused by the variation in the size of units which result from changes in the variability of the group, have been overcome by using a standard age group as the basis for the construction of all performance tests. Further improvements are easily possible and are certain to be made.

A third problem deals with the absolute value of the units. Variability units may well be of varying absolute magnitude. If so, devising a suitable mathematics for dealing with such units would be a prerequisite to the determination of ultimate educational law.

It may be well to note in passing that, theoretically, the score of a child in a spelling performance scale is not the number of words spelled correctly but the degree of difficulty of the last word spelled correctly. Thus, a fifth grade child who could spell "only" correctly but could not spell "forty," "saucer" or "too," would have a spelling ability of 30 units, while another child who could spell no words of greater difficulty than "too" would have a spelling ability of 60 units. Performance scales are used to measure the degree of development of ability. They are essentially classification tests.

The third method of test construction that will be discussed is the objective specification method. The units under such a method of construction are all equal, since each in terms of specifications is made to be just like the rest. The thing described in the specifications, however, is not judgment or performance or any function of ability, but the objective characteristics of the materials (subject-matter) with which the performance being measured deals. Equal-

ity of units in such tests, therefore, is based upon equal amounts of work. In doing work, time is always a factor. Accordingly, performance is measured by the amount of work done per unit of time and such tests are called rate tests. They tell nothing whatever about development of ability, but they do reveal the degree of skill exerted in the control of ability at a given level. Scores in rate tests reflect every change in any of the factors which cause or condition performance and must be corrected to standard conditions before they are comparable.

Scores in all rate tests have two dimensions, rate and quality or accuracy. Skill is never measured accurately by either rate or quality of performance alone, but by a score which is a function of both rate and accuracy.

DETROIT PUBLIC SCHOOLS

TEACHERS COLLEGE

Test 1. Addition — Standard

Instructions. When the examiner says "Start," work as many of the examples below as you can in the time allowed, but be sure you get the right answers. Do not hurry but work as rapidly and steadily as you can work correctly.

Each time the examiner says "Mark," draw a line around the example on which you are then working, go to the next. Do not finish an example after drawing a circle around it.

17	59	71	28	37	36	14	23
86	84	93	39	45	41	76	31
97	13	17	76	12	46	22	68
88	46	71	11	64	95	99	96
25	85	33	57	78	56	56	47
65	22	64	88	91	81	31	53
45	12	44	36	83	15	69	67
23	31	97	85	18	48	30	99
87	85	59	64	41	39	36	21
71	46	36	97	94	77	69	42
76	93	69	22	38	96	98	84
91	34	54	55	58	59	52	72

FIG. 10. Illustration of a rate test prepared by the objective specification method. See next figure.

The rate test chosen for illustration of the objective specification method of construction is an addition rate test. The specifications under which it was constructed are that each element or unit must (approximately) consist of

(1) Six two place numbers.

(2) Have 350 ± 50 as an answer.

(3) Contain two easy, six average and three hard combinations, defined as below.
(4) Contain not more than two pair of combinations whose sum is ten.
(5) Contain not more than one partial sum ending in zero.

OBJECTIVE SPECIFICATION METHOD

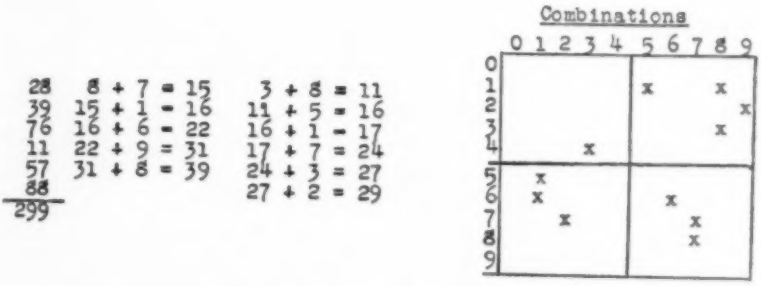


FIG. 11. Illustration of method of preparing each example shown in Fig. 10. The separate additions involved in the example are shown; also the analysis of these combinations as to their position. Each × represents a combination. 1 + 5 is indicated by the × immediately under 5.

To construct an example the 100 fundamental addition combinations are first divided into groups or classes (in this case three, "easy," "average" and "hard") by cross lines. These classes may be made as exact as desired. The illustration chosen represents a coarse grouping that defects caused by the coarseness may be evident. In the diagram one element of a combination is represented by the vertical axis and the other by the horizontal axis. Thus $\frac{3}{4}$ is represented by a cross in the row marked by four at the left and in the column under three (4 + 3) and for the purposes of this test is classed as an easy combination.

The second step is to build up, combination by combination, a six two-place number example. In all partial sums of 10 or more the ten's figure is disregarded and the combination is classified on the unit figures. Thus 16 + 6 is classified as 6 + 6, a hard combination, as it falls in the fourth division. Much patience and skill may be required in selecting and organizing combinations to make the resulting example conform even approximately to the specifications, especially if the specifications are very complex. Note that in the illustration given the sum is just outside the limit set by the specifications and the number of combinations of the various types is one "easy," seven "average" and two "hard." Nevertheless, it was included in the test as conforming *sufficiently* to the specifications for the purposes for which the test was to be used. Similar

irregularities will be found in each example. Nevertheless, the accuracy scores made by one hundred sixth grade children sufficiently skilful in addition to attempt ten or more problems in four minutes were as follows:

TABLE 1

PERCENTAGE OF RIGHT ANSWERS FOR EACH EXAMPLE FOUND IN THE PAPERS OF ONE HUNDRED SIXTH GRADE CHILDREN TAKING THE TEST UNDER STANDARD CONDITIONS AND POSSESSED OF SUFFICIENT SKILL TO DO AT LEAST TEN EXAMPLES IN FOUR MINUTES

No. 1—81 per cent.	No. 6—85 per cent.	
No. 2—79 per cent.	No. 7—89 per cent.	Mean value 83 per cent.
No. 3—85 per cent.	No. 8—81 per cent.	Mean deviation of distribution 2
No. 4—83 per cent.	No. 9—80 per cent.	
No. 5—81 per cent.	No. 10—79 per cent.	

In other words, the examples are equal, on the average, within 3 per cent. They could have been made equal within any desired limit, say one half of one per cent., by increasing the complexity of the specifications and by expending more time and care in their construction.

The objective specification method exactly reverses the method of evaluation used in the variability unit method of test construction. The latter determines the difficulty of the elements of a test from the performance of the children; the former makes the objective characteristics of the test elements equal and uses these objectively equal units to measure the behavior of children. Any change in performance, then, indicates that some change in either ability or the functioning of ability has taken place. Rate tests thus yield measures of performance in units of equal absolute objective value.

As with the other forms of test and scale construction, the objective specification method furnishes a number of unsolved problems. For one thing, the specifications on which the units are built must be adequate. They must deal with every characteristic of the subject-matter that affects the functioning of ability; otherwise the variations in value may be extreme. Thus, if the only specification was that each example should consist of six two-place numbers, the mean value of the units and the probable error of the distribution of the values would be greatly changed. For school subjects it is at present difficult to analyze subject-matter into the essential characteristics which must be controlled to make units equal.

A second problem is that of determining objectively the comparative difficulty of two rate tests. For instance, if one test is

composed of six two-place numbers and the other of nine three-place numbers, there is no known valid method of expressing the relative difficulty of the two units in terms of a single objective scale of difficulty. Indeed, except for Professor Thorndike's remarkable contribution,[7] the fundamental problem of what is meant by difficulty has received so far but very little attention from those interested in test and scale construction.

A third problem, which is common to all tests, but which is brought to light more clearly by rate tests than by other types, is that of validation. It is easy to call a test an addition test, but experiments soon prove that performance in such a test is merely the resultant of the action of a great complex of factors of which adding ability is but one. Educational science stands in great need of effective method of analysis of such complexes into unitary components which will "stay put." The situation in education closely resembles that in chemistry shortly before the discovery of oxygen and the development of the concept of elements. Every rate test measures performance only. There are those who maintain that the same is true of performance scales and of every other type of test; that the present definitions and measurements of intelligence and ability are only partially valid. I rate myself as a member of this group.

A fourth important problem is the correction of scores in rate tests to standard conditions. In handwriting it is difficult to tell whether a rate of 80 letters per minute at quality 60 Ayres is better or worse than a rate of 105 letters per minute at quality 35 Ayres until both have been reduced to either rate at standard quality or quality at standard rate. If it is found, other things being equal, that at a rate of 100 letters per minute both children write at quality 40, or that at quality 70 both children write at the rate of 70 letters per minute, it is easy to see that the children are equal in ability. At present, however, there are no valid means of making such comparisons.

Education as a science, therefore, must be judged to have taken two steps on the road to progress, but two steps only. She has glimpsed the vision of the objective impersonal determination of truth and has set her face in the right direction. She has learned how to construct crude but true measuring instruments which make possible the collection of scientific data and the raising of fundamental problems to consciousness. She is now busily engaged in taking the third step, improvement of her measuring instruments

[7] "The measurement of intelligence," *Psychological Review*, Vol. 31, No. 3, May, 1924.

and the accumulation of a mass of data. In the relatively near future she may be expected to take the fourth step, development of fundamental concepts.

III. Comparison of the Measurement Activity in the Physical and Educational Sciences

Before bringing this paper to a close, there is another phase of the situation which merits discussion. Many persons are deceived by appearances and judge that measurement in education and measurement in the physical sciences differ in kind as well as in degree. This is not so. In both, the instrumental errors are small and measurable. In both, the size of such errors is fixed by the time and effort expended in their reduction. In both, such errors have been reduced to limits adequate for effective generalization. In similar fashion, in both the personal errors of the observers are measurable and either compensating or removable by correction. In both, the objectivity of the things measured is high. A sample of handwriting or the sum in an addition test are as objective as a crystal or a flower. This point is frequently misunderstood. If a child writes, the rate of his writing can be determined to the exact number of letters written with very small instrumental and observational errors. The quality of writing can be determined easily to within one per cent. So far, there are no differences between measurements in the two fields. If, however, we examine the type of measurement used, a characteristic difference is evident at once. The method of measurement employed in the physical sciences is often direct; length is compared with length, force with force. When indirect measurement is used as in the measurement of an electric current, the complex situation which gives rise to the electric current-chemical action, electrodes, resistance, etc., is easily broken into fundamental elements, each of which is objective and may be maintained at constant conditions. Because of this constancy, the effects of the elements are additive and the swing of a galvanometric needle over a graduated scale reflects in an exact way the strength of the intangible electric current. In education, however, the complex causes which operate to produce behavior have not yet proved objectively divisible into controllable factors. For instance, it is known that performance is determined by both ability and effort, but no method has yet been discovered by which one may be controlled, while the effect of the other upon performance is determined. In other words, all measurement in education is indirect, and the apparent factors are not only many but overlapping. One psychologist has written:[8]

[8] J. A. Melrose, "Method for organic problems," *Psychological Review*, Vol. 32, No. 1, p. 74.

When Archimedes says, "Give me a place to stand and I will lift the world" his problem seems heroic because stated in heroic terms. Had he, however, tried to lift himself by his own bootstraps he would have faced the same dilemma. Psychology is in this dilemma. Its fulcrum rests upon its load.

In other words, the apparent difference between measurement in education and measurement in the physical sciences has its source, not in the differences in the technique of measurement, but in the more complex situation to which educational measurements are applied. Upon scientific analysis, educational products prove to be vastly more intricate, of vastly greater complexity, than had been supposed. The ultimate technique of analysis will have to be correspondingly more penetrating and subtle than for any science so far developed.

The measurement situation in education may be summarized by saying that the quantity actually measured is always some objective aspect of behavior in specific situations and under specific conditions. The quantity whose measurement is desired, however, is ability or general power to do; that is, power to perform, as measured under standard conditions, from which behavior in any specific situation may be predicted. Therefore, ability must always be *inferred* from behavior *and* conditions; it can never be measured directly.

In a general way the variable factors which affect the functioning of ability are known. They are:

A. External conditions; such as light, heat, materials, etc.
B. Physiological conditions of the organisms; such as vitality, fatigue, etc.
C. Ideational conditions of the organism; such as set, purpose and the like.
D. Emotional condition of the organism; such as fear, joy, etc.

However, knowledge of these factors and their effects rests at present upon general, and in the main, subjective estimation. Progress is dependent upon the reduction of the vague general concepts of forces and factors to specific concepts built upon objectively determined evidence and precise definition.

In similar fashion it is known that the general factors determining ability are:

A. The quality of the inherited mechanism as to composition, functional relationship between its parts, and powers of growth and adaptation.
B. The maturity of the organism, or the stage of development it has attained.
C. The training which the organism has undergone, or the amount, nature, intensity, recency of the practice in performing the given functions.

Capacity, maturity and training, or heredity, development and education, are thus vague general names for three great series of factors which also must be resolved into elements having stable manifestations before there can be effective determination of natural law in the educational field.

My thesis is that education is entitled to be ranked as a science, not because she is faced with intricate problems which can be solved only by rigid application of the inductive method, but because educationalists are actively attacking the problems of analysis by scientific methods, and inventing and using scientifically constructed instruments.

In support of this thesis I shall present by way of conclusion four specific illustrations of the methods of analysis that are being developed. While none of these methods are under satisfactory control, all of them are suggestive and promising. It is safe to predict that it is along such lines of analysis that progress will eventually be made.

My first illustration is from the unpublished studies of the supervisory department of the Detroit Public Schools. The supervisor of arithmetic[9] is at present attempting to analyze arithmetical ability into its elements and to determine the relation of such elements to the development of ability in students of various levels of intelligence.

In the test will be seen four different but related problems of the conventional type. The first is called "direct" because it nar-

Detroit Public Schools — Exact Science Department

MEASUREMENT OF EFFECTS OF COMPLEXITY OF THOUGHT PROCESS

Type	Problem	Answers			
1. Direct	Jack went to the store. He bought a pencil for 5¢ and a tablet for 8¢. The tablet and the pencil cost _____ cents.	5¢ / 3¢ / 8¢	8¢ / 5¢ / 3¢	5¢ / 8¢ / 13¢	8¢ / 3¢ / 5¢
2. Inverse	Jack went to the store. He bought a tablet that cost 7¢. He gave the storekeeper 10¢. Jack received _____¢ change.	7¢ / 10¢ / 17¢	10¢ / 3¢ / 7¢	10¢ / 7¢ / 3¢	7¢ / 3¢ / 10¢
3. Conditional	Helen has 9¢. She wants to buy a doll. The doll costs 15¢. Helen must have _____¢ more to buy the doll.	15¢ / 9¢ / 24¢	15¢ / 6¢ / 9¢	24¢ / 15¢ / 9¢	15¢ / 9¢ / 6¢
4. Abstract	A tablet cost 10¢. A pencil costs 6¢. A tablet costs _____¢ more than a pencil.	10¢ / 4¢ / 6¢	6¢ / 4¢ / 10¢	10¢ / 6¢ / 4¢	10¢ / 6¢ / 16¢

FIG. 12. For explanation of problem, see text. The child responds by drawing a line around the right answer.

[9] Louis Thiele, to whom the author is indebted for permission to use the data.

rates the elements of a simple experience in the order in which they occur. The two number facts—cost of pencil and cost of tablet—are both known before the need for their sum arises. The second problem is called "inverse," because after the first element is given, the sum in the form of 10 cents is presented and the child is called upon to resolve it into two elements before the second element, the change, can be determined. In the third problem nothing really happened. The girl has some money. She desires a doll. She knows the price. The student is thus forced to initiate an imaginative activity before a solution is possible. From one point of view the problem is identical with the second and not very different from the first, but from another point of view it is much more complex than either in that it calls for the manipulation of many mental images in grasping and controlling the situation. It involves elements of initiative and power which are not present in the preceding examples.

The fourth example omits all reference to persons and experience. It is a cold, impersonal statement of facts and relationships. There are no clues of emotional value to direct the thought process. The example calls for intellectual, abstract, generalized thinking.

When such a series of problems is presented to children in the upper third grade, the first grade in which the X or brighter children (upper 20 per cent. in intelligence) make a score of 100 per cent. on the first example, a comparison between the scores made by the X and Z groups (Z = lower 20 per cent. in intelligence) reveals at once differences in their powers. If the actual accuracy

Detroit Public Schools — Exact Science Department

MEASUREMENT OF EFFECT OF COMPLEXITY OF THOUGHT PROCESS
Through Comparison of Scores of X and Z Children in the Upper Third Grade
Scores of X Children Taken as 100% for Each Problem

Per cent Correct		Ratio Z/X	Type	0 10 20 30 40 50 60 70 80 90 100
X	Z		X	
100	92	92	Direct	
94	78	83	Inverse	
78	55	70	Conditional	
7*	44	56	Abstract	

FIG. 13. The table is to be read as follows: The X children in the upper third grade made 100 per cent. on problem 1, the Z children 92 per cent., so that the Z's children's performance was 92 per cent. as efficient as the X's on problem 1. The figure indicates that the less intelligent children differ more and more from the more intelligent as the complexity of the thought process involved in the test increases.

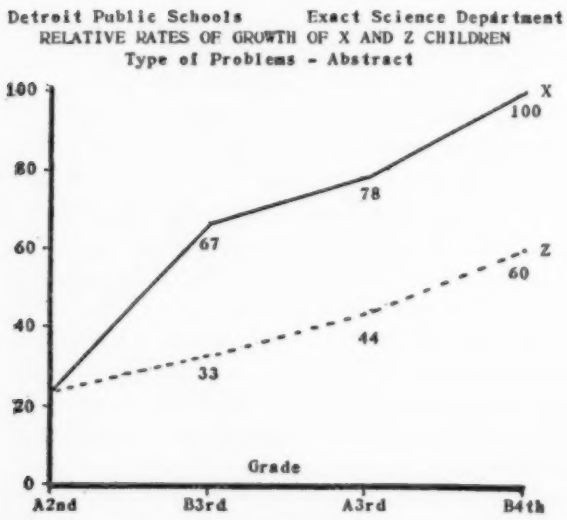


FIG. 14. The graph is to be read as follows: In the A 2nd grade the X and Z children made a score of 22 per cent. on Problem 4, the abstract example in Fig. 12. In the B 3rd grade the score of the X's was 67 per cent., of the Z's 33 per cent. The figure shows that the less intelligent children grow in mental power more slowly than the more intelligent.

scores of the X children is taken as a base (100 per cent.) for each example, the Z children perform 92 per cent. as well as the X children on the first example, but as the complexity of the thought process increases, the difference between the X and Z groups becomes larger and larger until for the abstract thinking demanded in the fourth problem the Z's are but 56 per cent. as efficient as the X's. It is possible to say, therefore, that the concept "intelligence" refers to some fundamental differences in children, much of which enables the individual to carry on abstract intellectual thought processes more readily than can be done with less intelligence.

This test may also be used to reveal another characteristic of intelligence. The lowest grade in which it can be successfully given is the upper second. In this grade the scores on the fourth or abstract problem are for both X and Z pupils below the probable score on the basis of chance alone (25 per cent.) there being but four possible ways in which the children could respond. With *one semester* of training, however, the scores of the X children (in B 3rd) change from 22 to 67 per cent., an amount of growth greater than that attained by the Z children (60 per cent.) after *a year and a half* of training (B 4th). One characteristic of intelligence

is, therefore, power to profit by experience. Under conditions of equal training, there should be an exact law expressing the relation between gain and intelligence. What that law is, however, can not be determined until more precise measures of both intelligence and ability to solve abstract problems have been developed.

My second illustration has been chosen to present a type of procedure which yields important results in the analysis of performance into ability elements. Tests 1, 3 and 5 are identical copies of a simple addition test, except that the examples in Test 1 are .25 inches apart, in Test 2 .50 inches apart and in Test 3 1.00 inches apart. Manifestly, the space between examples can not affect adding ability, so change of a single individual's score from one test to the next must be caused by the effect of the spacing. If one attempts to predict this effect, one is likely to prophesy lower scores for the more widely spaced tests. Certainly if the space between examples were increased enough (say to 100 feet), a child would be unable to complete as many examples in a given time as in Test 1. Actual trial with children, however, yields in many

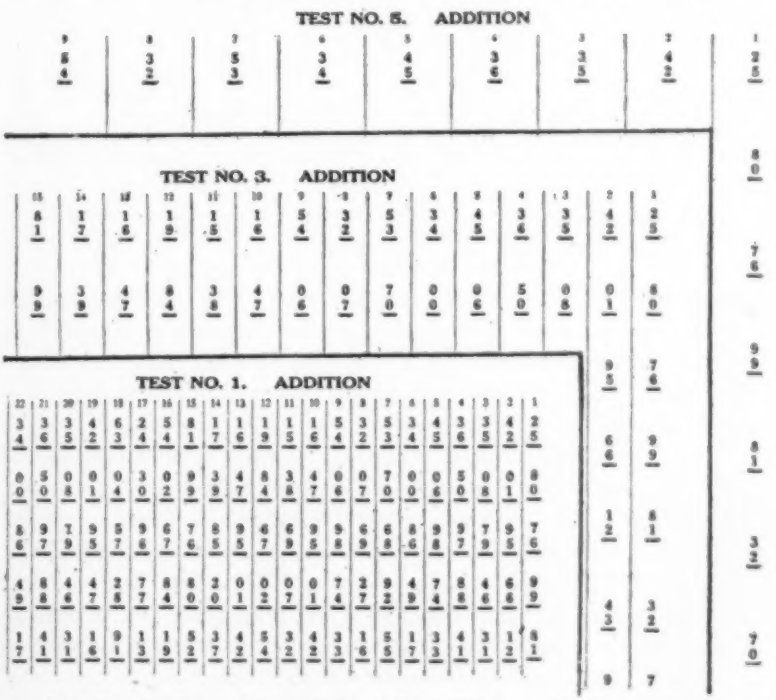


FIG. 15. Portions of three tests of the addition combinations superimposed to make comparison easy. The tests are made exactly alike except for one factor, the amount of space between the examples. In Test 1, the examples are approximately one quarter of an inch apart; in Test 2, half an inch, in Test 3, one inch.

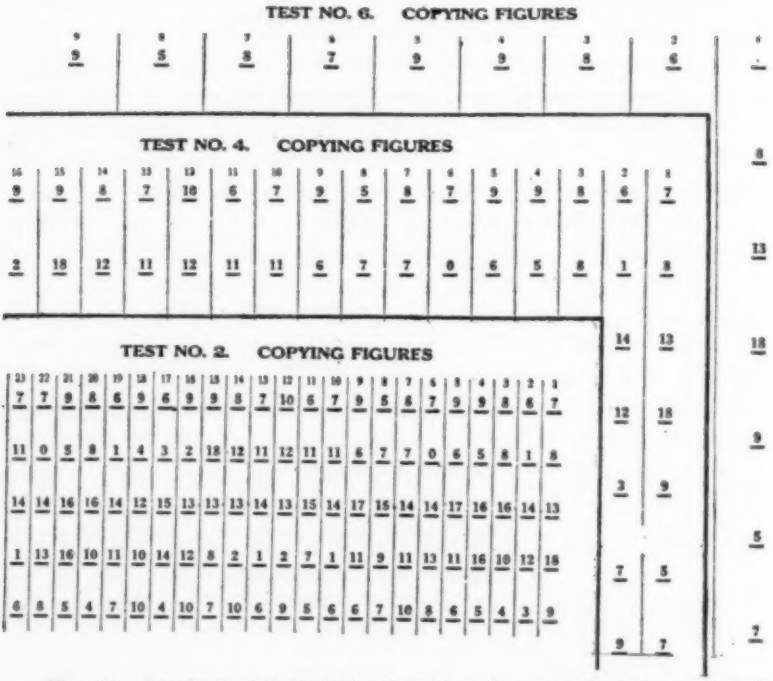


FIG. 16. Portions of three tests of copying figures made to be used with Tests 1, 3 and 5. The figures copied are the answers to the examples in Tests 1, 3 and 5. Performances in any one pair of tests are exactly the same except for one factor, adding. From the scores in a pair of tests, it is possible to derive a score for "pure" adding ability.

cases larger scores with Tests 2 and 3 than in 1. There is apparently greater freedom of movement and a stimulus to greater effort. A boy twelve years old in the seventh grade made scores (average of three trials) as follows: Test 1, 12; Test 3, 13; Test 5, 14.5; examples per minute.

Since after six years of practice in addition it is highly improbable that the boy's ability to add was changed by taking one or two brief tests, the three scores 12, 13 and 14.5 each contain as it were a constant measure, X, of ability to add combined with the effect of space, change in effort, practice effect, fatigue and similar factors. The problem, therefore, is to devise an analytical method which will enable the experimenter to extract a constant measure of adding ability from the complex scores.

The method of analysis is to construct three tests, 2, 4 and 6, similar in every particular to tests 1, 3 and 5 except in one respect, adding. Tests 2, 4 and 6 are copying tests. The numbers copied, however, are the answers to the examples in Tests 1, 3 and 5. The

outward performance in the two tests is, therefore, the same, the inward synthetic activity which produces the outward performance is also the same except that in the copying tests there is one less factor contributing to the resultant performance. The scores made by the boy previously mentioned were as follows: Test 2, 19; Test 4, 21.5; Test 6, 26. That is, for this boy the adding activity requires more time than mere perception.

For the sake of brevity I am omitting certain details of procedure necessary to standardize conditions and insure constancy of effort. It is enough to say that when the proper experimental conditions have been met, the effect of that single element in which the two tests differ may be found by dividing the product of the scores in the various pairs of tests by their differences.[10]

The result of applying this correction to the three pairs of scores obtained from this boy are 32.6, 32.9 and 32.8, results which are constant within less than 1 per cent. Unfortunately, this is a selected case. It is not possible at present to stabilize conditions for all children sufficiently to measure what might be called their "pure" adding ability, but by this method significant enough results have been secured in many fields to indicate something of its great analytical potentialities.

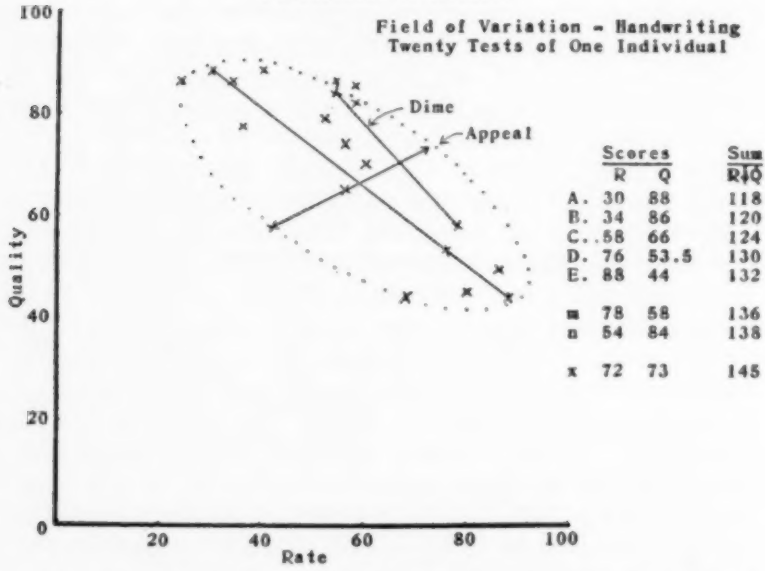
My third illustration will throw light upon some of the difficulties encountered in determining the effect of even such an objective and external factor as spacing through the complications of internal factors which also contribute to performance and disrupt the constancy of conditions.[11] It deals with two factors which I shall call the adjustment and the effort factors.

The figure is a graph of the scores of one individual in some twenty tests of penmanship under varying conditions and different examiners. Sometimes the members of his class were asked simply to write rapidly and well. Sometimes they were asked to write as rapidly as they could move their pens and to pay no attention to the legibility of their writing. At other times they were cautioned to do their very best and to pay no attention to their rate. At still other times various sorts of incentives were used, as money payment for improvement in both speed and accuracy, or the personal appeal of the teacher for utmost effort as a proof of their regard for her. The dotted line in the figure maps out a theoretical field of variation of performance which, it is believed, would have been obtained had the number of tests and conditions been, say, 2,000, instead of 20.

[10] Correction formulae for addition tests, *Teachers College Record*: 21, Jan. 1920, p. 1–24.

[11] From a series of investigations made possible by a grant from the Commonwealth Fund.

VARIATION IN PERFORMANCE CAUSED BY CHANGE IN FACTORS AFFECTING FUNCTIONING OF ABILITY



	Scores R	Q	Sum R+Q
A.	30	88	118
B.	34	86	120
C.	58	66	124
D.	76	53.5	130
E.	88	44	132
m	78	58	136
n	54	84	138
x	72	73	145

FIG. 17. The dotted ellipse represents a theoretical field of variation of score in handwriting of one individual tested under varying conditions; the crosses represent actual test results. Values A, B, C, D, E are scores which fall along the adjustment line; values mn represent the adjustment line when the child is putting forth more effort in response to a money incentive; X = score in response to an emotional appeal from the teacher. The minor axis of the ellipse represents the line of change in score caused by variations in effort put forth.

It should be noted that each of all these scores represents precisely the same ability in penmanship, if ability be defined in terms apart from the influence of special conditions. The child at will could and did in successive tests change from a score of 88 rate and 44 quality to a score of 30 rate and 88 quality and back again. Also, I wish to emphasize particularly that the instrumental and personal errors of each of these observations is approximately 2 per cent., so that the variation is in no way caused by inaccurate measurement. What we are dealing with here is varying performance accurately measured, not constant performance inaccurately measured. That is, the problem is one of analysis, not one of improvement of methods of measurement. The accuracy of the measurements exceeds greatly the effectiveness of our analytical technique.

Hypothetical analysis is possible to a degree, however. If the scores from Tests A, B and C are compared it will be found that they show a high degree of negative correlation. In general, there

is probably a law of adjustment for a mechanism which functions in performance and that law probably is that (for one individual) rate and quality are inversely proportional. Records are frequently secured, especially for adults, in which three or more scores maintain a constant relationship. If in a graph the same amount of space is used for both the rate and quality Ayres, one unit representing one letter per minute or one degree of merit on the Ayres scale, the most frequent angle made by the adjustment line with either axis is 45 degrees. In other words, the sum of rate and quantity is constant when rate is measured in letters written per minute and quality in terms of the Ayres handwriting scale. In the figure the major axis of the ellipse represents such an adjustment line, except that in this case it is not a 45° line and the scores of the various rates and qualities vary 7 per cent. either way from the average amount.

In one of the tests a strange examiner offered the children a dime if they would improve both their rates and qualities in a fast test and a slow test. The adjustment line of this particular pupil under this incentive is shown by the line marked "dime." Note that it is more clearly a 45° line and at a higher level than the major axis of the ellipse. The average sum of rate and quality for the major axis is 124; for the dime line is 137. The increase of 13 points is probably caused by the extra effort called out by the money incentive. In proof of this hypothesis the following facts are presented. After the strange examiner had departed, the regular room teacher told the children that she was deeply grieved to think that they would do so much better to win a dime or two than they would out of regard for her. She played upon their feelings with all the tricks of language at her command and then gave them another series of tests, appealing to them to prove they were not mercenary minded. The score 72–73 was the highest made and is 21 points higher than the mid-point, 124. On the other hand, the lowest score made on any test was one of a series given by the third of these strange examiners. The children became tired of the repeated tests and the low record was 24 points below the mid-point. The minor axis of the ellipse thus probably represents the range of variation in score caused by effort alone. Rate and quality are probably both directly proportional to effort and the elliptical field for any one student is the resultant of the play of the two factors, adjustment and effort.

On this theory, the fact that the apparent adjustment line of this individual is not a 45° line would be explained by saying that the directions for writing rapidly called out greater effort than the instructions to write well. However, there is at present no

COMPARISON OF COMPLEXITY OF PRODUCT MEASURED

Measure Used $\frac{\text{Semi-Annual Growth} \times 100}{\text{Standard Deviation}}$

Results			
Age	11	11.5	12
Height	73	72	63
Weight	68	65	57
Lung Capacity	59	55	46
Handwriting	53	48	41
Stanford	48	39	35
Intelligence	36	23	11

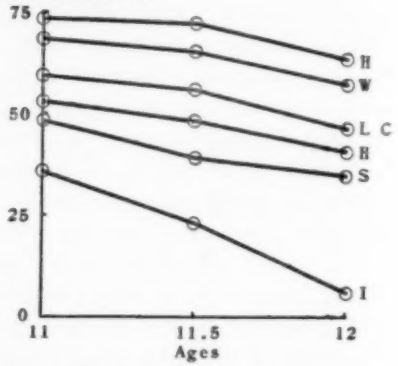


FIG. 18. The table is to be read as follows: If the ratio of semi-annual growth (×100) to the standard deviation of any trait is used as a measure of complexity, then for eleven-year-olds, height (73) is less complex than weight (.68). By this measure educational quantities are shown to be much more complex than physical quantities.

satisfactory method of measuring the effort component of a writing score and more exact determination of the relationship between these factors must await the invention of an adequate technique for measuring at least one of the pair singly.

My final illustration will deal with the complexity of educational products. I have adopted as a measure of complexity the percentage the semi-annual growth in mean score is of the standard deviations involved. Thus for age 11, the result for height is 73 per cent., for age 11.5, 72 per cent., for age 12, 63 per cent. Now height is a fairly stable characteristic, apparently determined largely by inherited forces of growth and affected relatively little by the incidents of life. Weight, on the other hand, varies with sickness, amount eaten, etc. Its index of complexity is lower. Lung capacity, the test of which involves voluntary effort, is lower still. Handwriting comes next. The composite score in the Stanford Achievement Test next, and intelligence scores based upon a composite of the army alpha and the national, lowest of all. At present the basic problem of education as a science is, therefore, the problem of analysis.

In view of this complexity and the fact of individual differences, the hope of rigid experimentation under the law of the single variable would seem to be slight. Actually, however, human nature is so variable that by matching pairs of individuals in a few significant traits two groups may be formed, composed of a very small

number of children, groups which nevertheless may be made as nearly equal as is desired.

In a group of 48 individuals the variations in handwriting ability from individual to individual was on the average 13 per cent. of the scores, the probable error of the distribution being 10.6 per cent. When pairs of individuals were matched in sex, age, intelligence, emotional stability and training, and groups of five formed, the differences in the average handwriting scores of the two groups, (scores of an ability in which they were not matched), fell to approximately 7 per cent. For groups of ten the difference in handwriting was a little more than 3 per cent., for groups of fifteen and twenty, less than 2 per cent., and for groups of twenty-four, but .2 of 1 per cent. On the other hand, the difference in the scores of the various groups in lung capacity, while not large (4 per cent.) were not affected by matching varying from slightly less than 2 per cent. to a little more than 5 per cent.

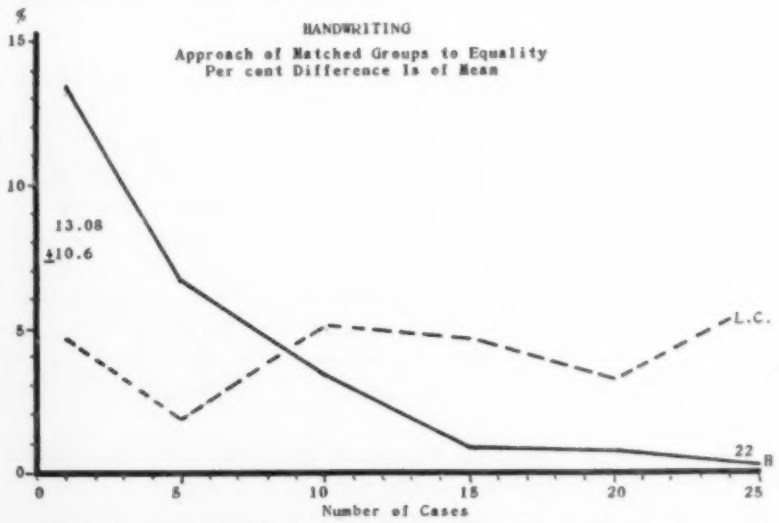


FIG. 19. The figure is to be read as follows: If any child is compared with any other child of the same age, sex, grade, intelligence and emotional rating, individual differences in handwriting ability are so great that the average difference for 48 cases was 13.08 per cent., half the cases falling within a range of 10.6 per cent. of this value. If instead of single scores the average score of matched groups of five such children are used, the difference in average of handwriting ability falls to 5.6 per cent., for groups of 10 to 3.3 per cent., etc.

By careful matching of pairs of individual children in essential characteristics it is possible to build up for experimental purposes two groups which shall be equal within any desired degree of accuracy.

H equals height. L. C. equals lung capacity.

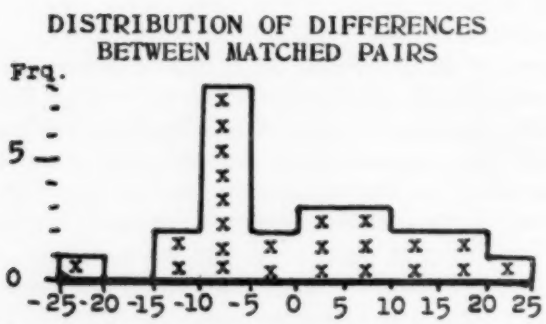


FIG. 20. Each X in the figure represents the difference in handwriting score of a pair of those individuals matched in sex, age, grade, intelligence and emotional rating which compose two groups of 24, whose average difference in handwriting was .2 per cent. The irregularities in the distribution show that the criteria used in matching were not completely adequate. In a control experiment changes in average values of groups to be acceptable would need to be confirmed by the tendency of the change in the differences of matched pairs.

The individual differences of the 24 matched pairs ranged from −21 to +21 but were fairly evenly distributed between the two groups. The excess of five differences at −5 and the deficiency at −15, however, mean that the criteria on which the individuals were matched are not quite adequate. Nevertheless, if one group were used as an experimental group and the other as a control group, any differences exceeding .5 of 1 per cent. resulting from the experimental factor could be detected. Thus, even with our present crude measuring instruments and our imperfect analytical technique, rigid experimental determination of the effects of such factors as method of teaching, selection of subject-matter, etc., is possible.

Education as a science, therefore, has measuring instruments and methods of experimentation more than adequate for present needs in the sense that many possible and valuable investigations have not yet been made. The greatest present-day lack is not for improved measuring instruments and new methods of procedure, but for adequately trained, scientifically minded men with time, opportunity and desire, to undertake the arduous labors of patient, painstaking research. This lack only time can supply. So I close as I began with the historical point of view and the prophecy that an important forward step in the formulation of fundamental concepts will be taken before 1945. This development will mark the beginning of the end of the transition period and will do much to establish education as a science even with those who can not now see the promise in the lusty infant because it is still wrapped in its swaddling clothes.

EVIDENCES FOR EVOLUTION

STATEMENTS PREPARED FOR THE DEFENSE COUNSEL, STATE OF TENNESSEE, VS. JOHN T. SCOPES

THE TRUTH OF EVOLUTION

By Dr. MAYNARD M. METCALF

THE JOHNS HOPKINS UNIVERSITY

INTELLIGENT teaching of biology or intelligent approach to any biological science is impossible if the established fact of evolution is omitted. Discussion of the methods by which evolution has been brought about is less essential, but the fact of evolution must be appreciated and the evolutionary point of view must be emphasized for any understanding of the growth of the universe, of the earth, of plants or animals; for any proper grasp of the facts of structure or function of living bodies as involved in medicine and in animal and plant husbandry; psychology, whether of normal or diseased minds, must constantly remember the processes of evolution; human societies, with their diverse customs, are unintelligible without the facts of their origins and changes, their evolution. God's growing revelation of Himself to the human soul can not be realized without recognition of the evolutionary method He has chosen. Teaching in any field that deals with living things is disgracefully, yes, criminally, inadequate if it omits emphasis upon evolution. An intelligent teacher could omit such emphasis only at the expense of his self-respect and of his moral integrity. Such teaching would be criminal malpractice just as truly as would be a physician's failure to follow established sound methods of treatment because of fear of persecution by ignorant neighbors. For a teacher to fail to bear testimony to essential scientific truth is as unworthy, as cowardly, as essentially sinful as for a man to fail to stand by his religion. Truth is one, whether scientific truth or religious truth, and it calls for loyalty from every worthy man. The fact of evolution—of man, of all living things, of the earth, of the sun, of the stars—is as fully established as the fact that the earth revolves around the sun. Change, growth, evolution, is a fundamental, a pivotal truth in all nature. Those familiar with the phenomena of nature testify with unanimity to this. The great mass of evidence of different sorts from different sources, when once seen, is overwhelmingly convincing to any normal, human mind. It can be only

the uninformed who fail to accept evolution as a fact established beyond doubt. On the other hand, there is great uncertainty as to the method by which evolution has been brought about. Many different factors have been in operation; among them probably the chief has been the mysterious intimate activities of the living substance itself about which as yet we know so little. As to the numerous "causes" of evolution and their relative importance there are about as many varieties of opinion as there are students of evolution. I am somewhat acquainted personally with nearly all the zoologists in America who have contributed extensively to the growth of knowledge in this field and I know many of the botanists and a goodly number of the geologists and I doubt if any two of these put exactly the same relative emphasis upon all the numerous interacting "causes" of evolution. But of all these hundreds of men not one fails to believe, as a matter of course, in view of the evidence, that evolution has occurred.

None of this, of course, has any bearing upon the question of God as the creator of the universe. It is only a matter of the method He has chosen in creation—whether immediate fiat or gradual growth accompanied by divergence. The evidence is overwhelming that the latter was and is His method. God is just as truly and just as intimately acting in the gradual growing of a plant from a seed or of a man from a fertilized egg as He would be in creating the full grown plant or man all at once in a thousandth part of a second of time.

There is no conflict, no least degree of conflict, between the Bible and the fact of evolution, but the literalist interpretation of the words of the Bible is not only puerile, it is insulting, both to God and to human intelligence.

But the fundamentalist would do much worse than insult God. He is in reality, although he doesn't realize this, trying to shut man's mind to God's ever-growing revelation of Himself to the human soul. He teaches, in effect, that God's revelation of Himself was completed long ago, that He long ago ceased to unfold His mind to men in new revelation. This is evil influence, criminal, damnable. Truth is sacred and to hinder men's approach to truth is as evil a thing, as unchristian a thing, as one can do. The thought that God is at odds with Himself, that his revelation of Himself to men of old is at variance with His works in nature is as blasphemous as it was for the Jewish leaders to say of Jesus that "He casts out devils through Beelzebub, the prince of the devils." Jesus made short work of this attack upon him.

No, the thing is not to attempt to guide God's self-revelation into channels of our own ignorant choosing, but is, rather, humbly

and in a wholly teachable spirit to seek His thought and Himself in nature, in history, in the vision of Himself He has given to men of old and is still giving to the humble-minded to-day. One of the greatest of God's revelations of Himself to men has come through His showing us His habit of producing results, by gradual growth, by evolution, rather than by immediate fiat.

Not only has evolution occurred; it is occurring to-day and occurring even under man's control. If one wishes a new vegetable or a new flower it is, within limits, true that he can order it from the plant breeder and in a few years he will produce it. Hundreds of new plants and animals have been and are being produced in this way. This is evolution of just the sort that has always occurred, only it is influenced by man's purpose. We can see evolution occurring in our experiment stations and our laboratories and we can control and modify the conditions of the experiments and can thus modify the resultant product to suit ourselves. Evolution is a present observable phenomenon as well as an established fact of past occurring. The organisms produced by this present-day controlled evolution in our experiments are as divergent from one another and from the original stock as are animals and plants in nature. The different kinds of domestic horses, produced by human experiment, differ far more than do the different kinds of horses found in nature. Domestic fowl under man's control have evolved into a large number of kinds far more widely divergent than are the wild kinds in the genus *Gallus* from which our domestic chickens came. The genus *Brassica,* plants belonging to the mustard family, include a number of different sorts of plants. One of these, *Brassica oleracea,* is the ancestor, the form from which man has evolved the cabbage, the cauliflower, kale, Brussels sprouts, Kohl rabi and the Swedish turnip, which differ among themselves far more than do the wild members of the genus *Brassica.* The same sort of thing is seen in hundreds of domestic animals and plants, dogs, cattle, sheep, pigeons, cucumbers, radishes, lettuce, dahlias, roses, wheats, corns, strawberries, peaches, apples, pears, etc. This is all true evolution and is going forward to-day with ever-increasing strides. To describe adequately the tremendous mass of phenomena which establish the fact of past and continuing evolution would require not a book or a series of books, but a library. In the main these evidences may be arranged in four chief groups: (1) The phenomena of comparative anatomy; (2) the phenomena of comparative embryology; (3) the phenomena of paleontology and geology, and (4) the phenomena of geographical distribution. Much in the fields of physiology, psychology and human cultures has very important bearing upon evolution.

(1) We can arrange plants and animals in a double parallel series showing increasing complexity of organization.

(2) In the development of an individual from egg to adult this individual passes through a series of stages of increasing complexity and this individual series in one of the higher organisms strangely parallels and agrees with the racial series first mentioned.

(3) In the fossiliferous rocks we find actual bodily remains of organisms of the past and these form a series showing increasing complexity within each taxonomic group, the animals and plants in the older rocks being more simple, while the successively younger rocks show more and more complex organisms in each group under observation.

(4) The distribution of animals and plants over the earth is such as to suggest strongly the origin of each group of animals or plants at some one place, and their gradual spread from that center, divergent evolution occurring while they are spreading. No other suggestion even plausible, let alone convincing, has been made to explain these phenomena. Evolution is the only key we can find.

In each of the four groups of phenomena mentioned there are many very striking things. One set of these things, in the first, morphological group, is that of the vestigial organs in animals and plants. There are in man, for example, very many structures of no conceivable present use, but showing resemblance to organs in other animals which are useful. The appendix vermiformis is one such structure, a mere vestige of an organ of great importance in some lower mammals. The human tail—bony coccyx with its rudimentary muscles—is another. The wisdom teeth of man are approaching a vestigial condition.

It is interesting to observe that an organ in one kind of animal may have a different use from the similar organ in a related animal. There are very few, if any, structures in man, for example, which do not show clear indications of relationship to, descent from, an organ of different use in some related animal. The lungs of man correspond to the swim bladder of fishes; hair has apparently been derived from tactile sense organs in the skin of aquatic vertebrates; certain bones connected with the human larynx were derived from the supporting arches in the bars between the gill slits of our aquatic ancestors; our teeth were once scales in the skin; and so on and so on. Probably there is no structure in the human body which was not at some time used for a different purpose. As the use of an organ changes, in evolution, its structure correspondingly changes and we see most complete series of intergrades between the earlier and the later conditions.

In all this discussion I have not used the word "species." There are no such things as species in nature. In nature we find different kinds of animals and plants. The words "species," "genus," "family," etc., are terms used to describe the fact that animals and plants differ among themselves and differ to different degrees. Those that are closely similar, that is closely related, we class in one species; those less closely related, but still not too different, we place in different species, putting the related species together in one genus; and so on. Species, genera and so forth, are man-made pigeon-holes in which to classify the real animals and plants seen in nature. I have recently made about 150 species of protozoa, but I have never made an animal. The word species is indefinable, and is used by biologists merely as a convenience, and it has wholly different meanings when applied to different groups of animals and plants. There are many genera of animals and plants in which most or all the species completely intergrade so that specific distinctions are purely artificial. This is true to large degree among the protozoan forms I have been studying recently. I have made species among them on the basis of distinctions far too minute to be considered for a moment as of "specific" value among, say, insects or mammals.

THE FACT, THE COURSE AND THE CAUSES OF ORGANIC EVOLUTION

By Dr. WINTERTON C. CURTIS

PROFESSOR OF ZOOLOGY, UNIVERSITY OF MISSOURI

At this point we may examine a common misunderstanding with reference to evolution and the work of Charles Darwin. Suppose we begin with an analogy, illustrating what may be termed the *Fact*, the *Course* and the *Causes* in a progressive series of events. A ship leaves a European port and sails across the Atlantic to New York harbor. We may distinguish between: (1) the fact that the ship actually crossed the ocean, instead of being "created" in the harbor of New York; (2) the course the ship may have pursued, whether direct or indirect, and the like; and (3) the causes that made the ship go, whether an internal propelling force like steam or electricity, an external force like wind or current or even direction by wireless. Compared with the doctrine of evolution, we have: (1) The fact of evolution, as representing the historical series of events; (2) the course followed in evolution, for instance, whether the land vertebrates arose from the fish-like ancestors, birds from

reptiles or the like; and (3) the causes of evolution or what made and makes it happen. These three aspects, like those in the voyage of a ship, are separate though related items. They must be constantly distinguished, if there is to be any clear thinking on this matter by one who is not a scientist.

It is now possible to explain the misunderstanding above cited. The historical fact of evolution seems attested by overwhelming evidence. Science has nothing to conceal, it stands "strong in the strength of demonstrable facts," and invites you to view the evidence. The course pursued by evolution is known broadly in many instances, but in the nature of the case the evidence is limited and many of the steps will always remain uncertain, without, however, a calling in question of the historic fact. The causes of evolution present the most difficult problem of all and the one regarding which we know the least. The recent strictures of Professor Bateson, which have been exploited by anti-evolutionists, were directed wholly at current explanations of evolutionary causation and the course of evolution. He affirmed his belief in the historic fact when he said "our faith in evolution is unshaken"—meaning by "faith," of course, *a reasonable belief resting upon evidence.*

That such an interpretation of Professor Bateson's views is the correct one appears from the following communication:

11 December 1922
The Manor House,
Merton
London, S. W. 20.

Dear Professor Curtis:

The papers you have sent me relating to the case of Mr. ———— give a curious picture of life under democracy. We may count ourselves happy if we are not all hanged like the Clerk of Chatham, with our pens and ink horns about our necks!

I have looked through my Toronto address again. I see nothing in it which can be construed as expressing doubt as to the main fact of Evolution. In the last paragraph (copy enclosed) you will find a statement in the most explicit words I could find, giving the opinion which appears to me forced upon us by the facts—an opinion shared, I suppose, by every man of science in the world.

At Toronto I was addressing an audience, mainly professional. I took occasion to call the attention of my colleagues to the loose thinking and unproven assumptions which pass current as to the actual processes of evolution. We do know that the plants and animals, including most certainly man, have been evolved from other and very different forms of life. As to the nature of this process of evolution, we have many conjectures, but little positive knowledge. That is as much of the matter as can be made clear without special study, as you and I very well know.

The campaign against the teaching of evolution is a terrible example of the way in which truth can be perverted by the ignorant. You may use as much of this letter as you like, and I hope it may be of service.

Very truly,
W. BATESON.

The paragraph to which Professor Bateson refers above is the concluding one of his address and runs as follows:

> I have put before you very frankly the considerations which have made us agnostic as to the actual mode and processes of evolution. When such confessions are made the enemies of science see their chance. If we can not declare here and now how species arose, they will obligingly offer us the solutions with which obscurantism is satisfied. Let us then proclaim in precise and unmistakable language that our faith in evolution is unshaken. Every available line of argument converges on this inevitable conclusion. The obscurantist has nothing to suggest which is worth a moment's attention. The difficulties which weigh upon the professional biologist need not trouble the layman. Our doubts are not as to the reality or truth of evolution, but as to the origin of *species*, a technical, almost domestic, problem. Any day that mystery may be solved. The discoveries of the last twenty-five years enable us for the first time to discuss these questions intelligently and on a basis of fact. That synthesis will follow on an analysis, we do not and can not doubt.

With this distinction between fact, course and causes clearly in mind, the significance of Darwin's work in the history of biological thought can be understood. Darwin's accomplishment was twofold. In the first place, he established organic evolution as the only reasonable explanation of the past history of living things. Secondly, he offered, in natural selection, what then appeared an adequate explanation for the origin of species and hence for the *causes* of evolution. Darwin's evolutionary argument in his "Origin of Species" was that one species could give rise to another "by means," as he believed, "of natural selection or the preservation of favored races in the struggle for life." If one species could be shown to give rise to another, the same process could be continued. No limit could be set. The types thus produced could depart indefinitely from the parent form. Once the mutability of species be admitted, the only reasonable conclusion is that evolution has taken place. His argument was supported by an immense collection of facts along observational and experimental lines. The total result was overwhelming, coming as it did more than one hundred years after the original promulgation of the theory of transmutation and its repeated rejection by the main body of naturalists. Evolution was accepted so quickly by scientists that the world was startled. This sudden conversion gave rise to the impression, even among scientific workers, that no serious contribution to evolutionary theory had been made before the work of Darwin. Such an impression does not represent the facts and it does grave injustice to the pioneer thinkers of the eighteenth century to whom we have alluded.

Darwin's second accomplishment, natural selection, was accepted by science as a causo-mechanical explanation of evolutionary

change. The cogent statement and the simplicity of the principle of selection were of great importance for its acceptance as the cause of evolution, along with the broader theory of evolution as the historic fact. Extended exposition of the selection process will not be attempted. It may be found in numerous elementary reference books and in the early chapters of the "Origin of Species." The tabulation known as *Wallace's Chart*, which is an admirable outline of the argument, may be cited in this connection:

WALLACE'S CHART OF NATURAL SELECTION

	Proved Facts	*Consequences*
A	Rapid Increase of Numbers	Struggle for Existence
B	Total numbers Stationary	
C	Struggle for Existence	Survival of the Fittest (Natural Selection)
D	Variation and Heredity	
E	Survival of the Fittest	Structural Modifications
F	Change of Environment	

The importance of Darwin's work in the history of scientific thought is that it *convinced science of the truth of organic evolution and proposed a then plausible theory of evolutionary causation.* Since Darwin's time, evolution as the historic fact has received confirmation on every hand. It is now regarded by competent scientists as the only rational explanation of an overwhelming mass of facts. Its strength lies in the extent to which it gives meaning to so many phenomena that would be meaningless without such an hypothesis.

But the case of natural selection is far different. Of recent years, this theory of the causes of evolution has suffered a decline. No other hypothesis, however, has completely displaced it. It remains the most satisfactory explanation of the origin of adaptations, although its all-sufficiency is no longer accepted. The initial step in evolution is the *appearance* of individual variations which are perpetuated by heredity, rather than the *selection* of variations after they have appeared. The interest of investigators has shifted to problems of variation and heredity, as exemplified by the rise of the science of genetics.

As a result of this situation, there has been much discussion among scientists regarding the adequacy of what is often referred to as the *Darwinian theory*, meaning *natural selection.* In condemning *selection* as an inadequate explanation of the problem, biologists have often seemed to condemn *evolution itself.* It is not strange that the layman, for whom Darwinism and evolution are synonymous terms, believes that evolution has been rejected when

he hears that belief in Darwinism is on the wane. He does not understand that what is thus meant by Darwinism is not the historic fact of evolution, but the proposed cause of evolution—natural selection. This point may not seem vital, but those interested in biological science frequently find the situation used to support claims that the entire concept of organic evolution has fallen into disrepute. There are many, even to-day, who rejoice at anything that appears to weaken this major generalization of biology.

Such then is the more strictly scientific status of the doctrine of evolution as a whole. The origin, by evolution, of the heavenly bodies and of our earth is evidenced by facts of astronomy and geology as set forth in any elementary treatise on these sciences. Inorganic evolution or the modification of non-living matter is thus supported by science and does not find serious opposition in the public mind. Organic evolution or the origin of animal and plant life receives a similar support from the facts of biology. If the origin of man were not involved, there would be presumably little serious opposition from non-scientific sources at the present day.

Human Evolution

But with the evolution of all other living things, both animal and plant, overwhelmingly attested by the facts, it is not only impossible but puerile to separate man from the general course of events. Moreover, the evidence for man's origin is becoming clearer year by year. Comparative anatomy, embryology, classification, physiology, geographical distribution, fossils and the existing races of mankind tell the same story for man as for the rest of the animal world.

Huxley's essay, entitled "Man's Place in Nature," presents in a masterful manner the anatomical evidence for our kinship with the four species of tailless apes—the gibbon, gorilla, orang and chimpanzee—and his most significant conclusions are even more strongly established at the present day. If creation occurred "at 9:00 A. M., on October 23, of the year 4004 B. C." as part of the divine plan, it is amazing that such success should have dogged the steps of the students of human skeletal and cultural remains during the last half century. The skeletons in part or in whole are known for a number of sub-human races and a vast array of implements and other remains, all showing a progressive advancement. By another fifty years, it seems safe to expect that much more of the story will be unveiled. It is further amazing that investigations in Egypt show the existence of a flourishing civilization in the Nile Valley as early as 5000 B. C., and back of this a gradual development from the barbarism of the stone age.

On man's intellectual side, psychology is making increasingly evident the essentially animal foundation of human intelligence. Man's claim to importance in the universe revealed by science lies not in the pretense that this planet was created for his convenience, but in the claim that he transcends the material universe in so far as he comprehends it. And the method of such comprehension that dominates modern thought is the method of science, not that of theology.

The question of human beginnings is one that is open to investigation like any other historic or prehistoric event. In this connection a quotation from a famous essay by Herbert Spencer, published in 1852, is appropriate:

> Those who cavalierly reject the Theory of Evolution, as not adequately supported by facts, seem quite to forget that their own theory is supported by no facts at all. Like the majority of men who are born to a given belief, they demand the most rigorous proof of any adverse belief, but assume that their own needs none. Here we find, scattered over the globe, vegetable and animal organisms numbering, of the one kind (according to Humboldt) some 320,000 species, and of the other some 2,000,000 species (see Carpenter); and if to these we add the numbers of animal and vegetable species that have become extinct, we may safely estimate the number of species that have existed, and are existing, on the earth, at not less than ten millions. Well, which is the most rational theory about these ten million of species? Is it most likely that there have been ten millions of special creations? Or is it most likely that by continual modifications, due to change of circumstances, ten millions of varieties have been produced, as varieties are being produced still?

And, one might add, if the evidence indicates that all other species have arisen by evolution, it is probable that man, whose bodily structure and functions are so nearly identical with those of the mammalia and particularly the primates—that man arose in a different fashion. We have, moreover, as above indicated, the positive evidence to support this general presumption.

Having outlined the evidence for human evolution and stated the presumption in its favor, let us turn to the evidence for special creation, as found in Genesis. Science and common sense alike inquire regarding the nature and sources of this account, if it be regarded as a true statement of the facts. Science faces the matter squarely, desiring only the right to investigate and draw unprejudiced conclusions. The results of such investigations are not in doubt. It appears that the races about the eastern Mediterranean, like other primitive peoples, had their traditions of the origin of the world. The story in Genesis apparently descended to the early Hebrews and to their neighbors in Mesopotamia from a source far antedating the appearance of the Jews as a people and their sacred writings. Archeology and ethnology most reasonably indicate that

in its origin this Hebrew-Babylonian tradition may be compared with the stories of many other primitive peoples. We take the story in Genesis seriously as an account of prehistorical facts, because it is *our* story of creation passed down by tradition from *our* fathers. It is and will remain sacred and interesting, because it has been woven into the thought of western culture for almost two thousand years and because of its intrinsic literary and moral qualities.

But the past history of events, whether of human or animal origins, is subject-matter for scientific inquiry, and the answer of science is evolution. The very great antiquity of man, the existence at an earlier period of beings, man-like, but intermediate between man and other primates, together with the facts of man's anatomy, his embryology, his physiological reactions, even his mentality, all point to his bodily kinship wth the rest of living nature. It is not that men came from monkeys, but that men, monkeys and apes all came from a common mammalian ancestry millions of years in the past.

It is more reasonable to believe that the Bible is a human document, representing the history of an advance from the concept of a barbarous and vengeful Jehovah of the earlier Old Testament, through the God of righteousness and justice of the later prophets, and culminating in the concept of a Father as preached by Jesus of Nazareth.

In the foregoing statement we have considered the intellectual aspects of the doctrine of organic evolution. There remain its social aspects. Evolution is one of the basic concepts in modern thought. Suppression of a doctrine established by such overwhelming evidence is a serious matter. From the standpoint of the teacher the situation has more than academic interest.

Evolution has been generally accepted by the intellectually competent who have taken the trouble to inform themselves with an open mind. The following letter was written in response to a request to state his position, it having been alleged that he was not a believer in organic evolution:

Washington, D. C.
29th August 1922

My dear Professor Curtis:

May it not suffice for me to say, in reply to your letter of August twenty-fifth, that of course like every other man of intelligence and education I do believe in Organic Evolution. It surprises me that at this late date such questions should be raised.

Sincerely yours,
WOODROW WILSON

Professor W. C. Curtis,
Columbia, Missouri.

In view of all the facts, may we not say that the present storm against organic evolution is but an expression of malign influences of prejudice and ignorance, hostile to what we may envision as the high destiny of our western world.

EVIDENCES FROM COMPARATIVE ANATOMY

By Dr. H. H. NEWMAN

PROFESSOR OF ZOOLOGY, UNIVERSITY OF CHICAGO

THE foundation stones of comparative anatomy are the principles of homology and of analogy. The former implies heredity and the latter variation.

THE PRINCIPLE OF HOMOLOGY

Any one who has at all seriously studied comparative anatomy must have been impressed with the fact that the animal kingdom exhibits several distinct main types of architecture, each of which characterizes one of the grand divisions of the kingdom. Within each of these great assemblages of animals characterized by a common plan of organization there are almost innumerable structural diversities within the scope of the fundamental plan. These major or minor departures from the ideally generalized condition remind one of variations upon a theme in music; no matter how elaborate the variation may be, the skilled musician recognizes the common theme running through it all. This fundamental unity amidst minor diversity of form or of function is looked upon as a common inheritance from a more or less remote ancestor. In animals belonging to the same group and therefore having the same general plan of organization we find many organs having the same embryonic origin and the same general relations to other structures, but with vastly different superficial appearance and playing quite diverse functional rôles. Such structures are said to be homologous.

A common example of homologous structures is presented by the fore limbs of various types of backboned animals (vertebrates): such, for example, as that of man, that of the whale, that of the bird and that of the horse. The arm of man is by far the most generalized of these; it is not far from the ideal prototypic land vertebrate fore limb, in that it is not specialized for any particular function but is a versatile tool of the brain. The flipper of the whale is a short, broad, paddle-like structure, apparently without digits, wrist, fore arm or upper arm; but on close examination it is seen to possess all these structures in a condition homologous almost bone for

bone and muscle for muscle with those of the human arm. The wing of the bird, a highly specialized organ of flight, appears superficially to have nothing in common with the arm of man; but a study of its anatomy shows the same bony architecture and muscle complex, modified rather profoundly for a different function and with the thumb and two of the fingers greatly reduced or entirely unrepresented in the adult stage. The fore leg of the horse is a specialized cursorial appendage, and in accord with this function has but one functional toe with a heavy toe-nail or hoof. Two other toes are represented by the so-called splint bones, mere vestiges of once useful structures. In other respects the horse's leg is quite homologous with that of other land vertebrates. The evolutionary explanation of the fact that these several types of limbs (each playing an entirely different rôle in nature and each so unlike the other in form and proportions) have the same fundamental architecture is that they have all inherited these characters from some distant common ancestor. In each case the inheritance has undergone modification in harmony with the life needs of the organism. This of course implies descent with modification, which is no more or less than evolution.

An equally significant situation comes to light in connection with the hind limbs of vertebrates. The leg of man, a specialized walking appendage, is much less versatile than is the arm, yet it is closely homologous with the latter. The hind limb of the whale is in some species entirely wanting in the adult or else is in vestigial condition. The leg of the bird is decidedly reptilian in structure and is believed to have retained in large measure the characteristics of that of the supposed reptilian ancestors. The hind limb of the horse, though somewhat stronger and heavier than the fore limb, resembles the latter closely both in form and function. Snakes are typically limbless vertebrates, but the python has small but clearly defined hind limbs, somewhat reduced in number of bones and almost entirely hidden beneath the scaly integument.

No other attempt to explain homologies such as those briefly outlined above has been made except that of special creation, and this implies a slavish adherence to a preconceived ideal plan together with capricious departures from the plan in various instances. A systematic attempt to apply the special creation concept to all cases of homologies involves one in the utmost confusion of ideas and leads almost inevitably to irreverence, which is abhorrent to evolutionist as well as to special creationist.

Vestigial Structures

These may be defined as functionless rudiments of structures whose homologues are found in a functional state in other members

of a group with a common architectural plan. Thus the hind limbs of the whale and of the python, the thumb of the bird, the splint bones of the horse, are vestigial homologues of structures well developed in more generalized groups of vertebrates.

The case of the hind limb vestiges in the various species of whales may be emphasized as a crucial one. Several different degrees of rudimentation are found in different types of whales, ranging from a state in which the pelvic bones and those of most of the leg are clearly recognizable as such down to one in which these bones are entirely absent in the adult condition. In the cases where the bones are obvious, the situation is just this: deeply buried beneath the thick cushion of blubber in the pelvic region there lies a little handful of bones, ridiculously minute in comparison with the giant proportions of the other parts of the skeleton. These bones are immovable because their muscular connections are atrophied; they do no service in supporting the frame of the animal; in short, they can not possibly function as bones at all. The somewhat puerile argument of the anti-evolutionist that these vestigial limb bones play some useful though unknown rôle, else they would never have been created, can not seriously be entertained in this case, for what can they make of the fact that some whales entirely lack these structures? More difficult even than this for the special creationist to explain is the fact that, even in those whales that lack vestigial limb bones in the adult condition, posterior limb buds appear in the early embryonic period and then slowly atrophy. The case just described is in no way exceptional or peculiar. It is, on the contrary, quite typical of a very general phenomenon.

Vestigial Structures in Man

There are, according to Wiedersheim, no less than 180 vestigial structures in the human body, sufficient to make of a man a veritable walking museum of antiquities. Among these are: the vermiform appendix; the abbreviated tail with its set of caudal muscles; a complicated set of muscles homologous with those employed by other animals for moving their ears, but practically functionless in all but a very few men; a complete equipment of scalp muscles used by other animals for erecting the hair but of very doubtful utility in man even in the rare instances when they function voluntarily; gill slits in the embryo, the homologues of which are used in aquatic respiration; miniature third eyelids (nictitating membranes), functional in all reptiles and birds, greatly reduced or vestigial in all mammals; the lanugo, a complete coating of embryonic down or hair, which disappears long before birth and can hardly serve any useful function while it lasts. These and numerous other

structures of the same sort can be reasonably interpreted as evidence that man has descended from ancestors in which these organs were functional. Man has never completely lost these characters; he continues to inherit them, though he no longer has any use for them. Heredity is stubborn and tenacious, clinging persistently to vestiges of all that the race has once possessed, though chiefly concerned in bringing to perfection the more recent adaptive features of the race.

Homology versus Analogy

It is quite common to find different animals with certain structures that look alike and function alike but are not homologous. The eye of the octopus, a cephalopod mollusc, has a chorion, a lens, a retina, an optic nerve and a general aspect decidedly like that of a fish. As an optical instrument it must obviously function in the same manner as does the eye of an aquatic vertebrate; but not one part of the eye of a cephalopod is homologous with that of a vertebrate. Because these two types of eye look alike and function alike, but arise from quite different embryonic primordia adapted to meet a common function, they are known as analogous structures. They are to be sharply contrasted with homologous structures, which may be widely different in form and function so long as they arise from equivalent embryonic primordia. Both homologies and analogies imply changes in relation to the environment and therefore plainly favor the idea of descent with modification.

Connecting Links

If one group of animals has been derived by descent from another there should be some forms more or less intermediate between the two and with some characteristics of both groups. Many such connecting links actually exist at the present time. Almost every order of animals possesses some primitive members that have doubtless evolved at a slower rate than their relatives and have on that account retained a larger measure of ancestral traits than have the more typical representatives of the group. Thus there is a group of primitive annelid worms, represented by Dinophilus, Protodrillus and Pollygordius that serve partially to bridge the gap between the two grand divisions, annelids and flatworms. The case of the several species of Dinophilus is especially noteworthy, for these little animals are so evenly balanced between the characteristics of one phylum and those of the other that some authors place them among the flatworms, others among the annelids and still others are inclined to place them in an anomalous group by themselves. There is an interesting genus of primitive centipedes, called Peri-

patus, which possesses about as many annelid features as arthropod features. Among vertebrates we have the familiar example of the lung fishes with both the gills of fishes and lungs homologous with those of land vertebrates. And finally, we may mention those curious egg-laying mammals, monotremes, of Australia and New Zealand, which though obviously mammalian in most respects, possess, in addition to laying eggs after the fashion of reptiles, many other decidedly reptilian traits. The reader interested in following up in more detail this interesting branch of comparative anatomy will find the subject skilfully handled by Geoffroy Smith in a volume entitled "Primitive Animals."

Comparative anatomy is a mature and well-organized science and involves a vast amount of technical data. No one but a trained comparative anatomist can reasonably be expected to appreciate the dependence of this subject upon the principle of evolution. Without evolution as a guiding principle comparative anatomy would be a hopeless mass of meaningless and disconnected facts; with the aid of the principle of homology, an evolutionary assumption, it has grown to be one of the most scientific branches of biology. This may be taken as an illustration of the nature of the proof of organic evolution; that when it is used as a working hypothesis or guiding principle, it really works in that it is not only consistent with all the facts, but lends significance and interest to facts that would otherwise be drab and disconnected.

Evidences from Classification

The object of classification is to arrange all species of animals and plants in groups of various degrees of inclusiveness which shall express as closely as possible the actual degrees of relationship existing between them. In pursuance of this object we begin by grouping together as one species all animals that are essentially alike in their anatomical details. As an example of the methods of classification we may take the following familiar instance: the European wolf is a particular kind of animal constituting a species called lupus (the Latin word for wolf) all members of which are more like one another than they are like wolves of other sorts, for the reason that they have a common inheritance. There are not a few other species of wolves, each given a Latin name, and all these wolf species, including dogs (believed to be domesticated and therefore highly modified wolves) are placed in one genus, Canis. Several other genera of more or less wolflike animals, such as jackals and foxes, are grouped with the genus Canis and constitute the family Canidae, the assumption being that they are all the diversified descendants of some common wolflike ancestor. Other families,

such as the Cat Family (Felidae), the Bear Family (Ursidae) and several other families of terrestrial beasts of prey, constitute the suborder Fissipedia. These in turn are grouped with the marine beasts of prey, such as seals, sea-lions, walruses (suborder Pinnipedia) to form the mammalian order, Carnivora. Several other orders of animals with many characteristics in common are combined to form the class Mammalia, which is one of several classes belonging to the subphylum Vertebrata, a branch of the phylum Chordata. A phylum is one of the grand subdivisions of the animal kingdom and is made up of species with the same fundamental plan of organization, the common features of which are believed to be derived from a common ancestral type.

The underlying assumption of classification is the same that underlies comparative anatomy; that degrees of resemblance run parallel with degrees of blood relationship, that the most nearly identical individuals are most closely related and that those that bear the least fundamental resemblance to each other are either not genetically related at all or else had a common ancestor far back in the misty past when animal life was in process of origin. We have already shown that this assumption holds good in all cases where it has been possible to put it to the test. No further justification need be offered in this place for making use of the only adequate instrument of classification: the principle of homology.

What is a Species?

The species is the unit of classification, but there is serious doubt as to whether species have any reality outside of the minds of taxonomists. Certainly it is extremely difficult, if at all possible, exactly to draw sharp boundary lines between closely similar species. When we examine a large number of individuals belonging to a given species we find that there are no two exactly alike in all respects. As a rule there is a wide range of diversity within the limits of the group we call a species, and the extreme variants are often so unlike the type form that were it not for the intergrading steps between them they would often be adjudged distinct species. Moreover, the species of a prosperous genus are so variable that it becomes an almost impossible task to determine where one species ends and another begins, so closely do they intergrade one into another. A species, then, is not a fixed and definite assemblage such as one would expect it to be if specially created as an immutable thing. On the contrary, intensive study of any widely distributed species gives the impression of an intricate network of interrelated individuals changing in a great variety of ways.

The completed classification of any large group, such as the vertebrates, presents itself as an elaborately branching system whose resemblance to a tree is unmistakable. The phylum branches into subphyla, some of the latter into several classes, classes into orders, orders into families, families into genera, genera into species, species into varieties. We may compare the phylum to one of the main branches coming off from the trunk, while the varieties may be thought of as the terminal twigs. This tree-like arrangement is exactly what one would expect to find in a group descended from a common ancestry and modified along many different lines. It is in reality a genealogical tree. If this striking arrangement is a part of the plan of special creation it is indeed strangely unfortunate that it speaks so plainly of descent with modification.

Man's Place in the System of Classification

There is no greater difficulty in connection with the classification of man than in that of any other living species. Indeed there are scores, even hundreds, of species whose exact affinities with other groups are far less obvious than those of the human species. Anatomically, the genus Homo bears a striking resemblance to the anthropoid apes. Bone for bone, muscle for muscle, nerve for nerve, and in many special details, man and the anthropoid apes are extremely similar. Homologies are so obvious that even the novice in comparative anatomy notes them at a glance. Man is many degrees closer anatomically to the great apes than the latter are to the true monkeys, yet the special creationist insists upon placing man in biological isolation as a creature without affinities to the animal world. If a man is a creature apart from all animals it is extremely difficult to understand the significance of the fact that he is constructed along lines so closely similar to those of certain animals; that his processes of reproduction are exactly those of other animals; that in his development he shows the closest parallelism step for step to the apes; that his modes of nutrition, respiration, excretion, involve the same chemical processes; and that even his fundamental psychological processes are of the same kind, though differing in degree of specialization, as are those of lower animals.

Comparative anatomists recognize man as a vertebrate, for he has all the characteristic features of that group. He is obviously a mammal, for he complies with qualifications of that class in having hair; in giving birth to living young after a period of uterine development; in suckling the young by means of mammary glands; in having two sets of teeth, one succeeding the other; in having the teeth differentiated into incisors, canines and molars; and in many other particulars of skeleton, muscular system, circulatory system,

alimentary system, brain and other parts of the central nervous system. Among mammals, man belongs to the well-defined order of Primates, an order anatomically about half way between the most generalized and the most specialized of the mammalian orders. Apart from his extraordinary nervous specialization, man is a relatively generalized mammal as compared with such highly specialized types as, for example, the whales. The older taxonomists place man and the other primates at the top of the genealogical tree, assigning to him the central tip of the central branch as though the goal of all organic evolution were man. Accordingly, those mammals such as the whales, which are least like man, were considered the lowest members of the class. There has been within recent years a pronounced reversal of this anthropocentric point of view, which has resulted in a complete revision of the arrangement of mammalian orders, with the Insectivora the lowest, the Cetacea (whales) the highest, and the Primates about intermediate in systematic position.

The order Primates consists of two suborders—Lemuroidea and Anthropoidea. The lemurs or half apes are small arboreal animals with somewhat squirrel-like habits but with flat nails and certain other primate characters. They serve to link up the Primates with the most primitive of the mammalian orders, the Insectivora, which are now believed, on anatomical and paleontological grounds, to be ancestral not only to the primates but to most of the other modern mammalian orders. The anthropoid or man-like Primates are divided into four distinct families: the Hapalidae or marmosets; the Cercopithecidae or New World monkeys; the Simiidae or anthropoid apes; and the Hominidae or men. The family Hominidae includes four genera: The genus Pithecanthropus, represented by the fragmentary remains of an extinct Javan ape-man, the genus Paleanthropus, the genus Eanthropus and the genus Homo, including in addition to the existing species Homo sapiens, several different extinct human species known as the Dawn Man, the Neandertal Man, the Rhodesian Man and others.

The species Homo sapiens consists of at least four sub-species or major varieties, each consisting of numerous minor races and admixtures of these. This high degree of diversity within the species is evidence of rapid evolution. If a little over four thousand years ago, as the special creationists claim, one man was created and has become the ancestor of all men living to-day, evolution must have gone on at an extremely rapid rate in order to have produced so many widely different races, for there could scarcely have been more than one hundred and twenty generations in that time. If species are believed to be immutable it is difficult to understand why man should be such a diversified group as he is.

ORGANIC EVOLUTION FROM THE POINT OF VIEW OF THE SOIL INVESTIGATOR

By Dr. JACOB G. LIPMAN

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THE student of soils is obliged to consider the materials from which they are made. These materials are represented by rocks and minerals, and by the remains of plants, animals, insects, bacteria and other microorganisms. The change of rocks into soils is a slow and gradual process. In the older geological ages the mantle of soil covering the rocks was not as thick as it is to-day. Going back far enough, we come to the time when the depth of soil was not great enough to support plants of any but very primitive forms. Like plants and animals, our soils had to pass through a long period of change to support the varied forms of life on the earth. A direct relation may be traced between soils, plants and animals in the evolution of organic life.

Among the early forms of life there were bacteria capable of developing in a purely mineral medium. Such forms are still found in the sea, in mineral springs and in soils. Some of them can obtain the energy for their life processes by oxidizing hydrogen gas, methane (marsh gas), carbon monoxide, sulphur, sulphuretted hydrogen, iron and even carbon. In the primitive seas, and on the rock surfaces, these simple forms of life prepared the way for the more highly organized beings. Some bacteria are able to manufacture nitrogen compounds out of the simple nitrogen gas of the air. They thus supply material out of which the protoplasm of plant and animal cells is made. Other bacteria convert the nitrogen of plant and animal substances into ammonia and nitrates. Mineral acids, like nitrous, nitric, sulphuric and phosphoric, are partly, if not entirely, the products of bacterial activity. Carbon dioxide is generated in enormous quantities through the activities of microorganisms. In the course of ages the by-products of microbial activity served to dissolve enormous quantities of rock material, and this dissolved material started on its way to the sea. Silicates, phosphates, nitrates, sulphates and carbonates went to supply the building stones for the bodies of marine organisms. Some of the salts dissolved from the rocks ultimately became the source of salt deposits, such as rock salt, gypsum, potash, salts, limestone, etc. Bacteria are thus recognized as the primary or secondary cause of extensive mineral deposits, in other words, as geological agents of importance. By way of example, mention may be made of the potash deposits

of certain European countries, estimated to be twenty million years old. The green sand formation of New Jersey and states further south originated in the sea about ten million years ago. The phosphate deposits of Central Tennessee are derived from limestone rock fifty million years old at the very lowest estimate. The extensive deposits of coal represent the remains of ancient vegetation. We are now burning coal derived from plants that grew at least twenty million years ago. The coal deposits contain nitrogen which to-day is the source of fertilizer. In making coke, illuminating gas and other products from coal, a large part of the nitrogen is saved and converted into ammonia for refrigeration and fertilizer purposes. We know of extensive deposits of sulphur which originated millions of years ago and which to-day are used for industrial and agricultural purposes. In a similar way, mention may be made of deposits of iron ore, gypsum, or limestone, in the formation of which bacteria played an important part.

To-day, like many millions of years ago, bacteria are busy creating conditions necessary for the growth of plants and animals. Bacteria are responsible for the circulation of carbon and nitrogen in nature. The material of plant and animal bodies is used over and over again, and processes of decay must go on in order that the carbon, nitrogen, sulphur, phosphorus, lime and other elements locked up in the bodies of plants and animals may be released for the development of countless generations of living things. It has been truly said that we may have in our bodies to-day the carbon, or the nitrogen, which were once in the bodies of the kings of Egypt or of living organisms of whose origin and history we know nothing.

After the lowly bacteria and other microscopic forms of life had lived and produced extensive changes on land and in the sea, conditions became more favorable for the growth of plants. The primitive forms of plant life gradually developed into more perfect organisms, until the mosses, ferns, cycads gave way to flowering plants, perhaps ten million years ago at a very conservative estimate. In some way bacteria learned to establish a partnership with some kinds of plants, such as clover, alfalfa, soy beans, etc. These plants, together with the bacteria, are the important factors in our agriculture as regards the maintenance of a supply of nitrogen in our soils.

Thus plants had to develop both as to quantity and quality in order that there might be sufficient food for the advancing forms of animal life. One may properly speak of the genesis and evolution of soil as one would speak of the genesis and evolution of plants and animals. Man has learned to use this knowledge to improve his condition, and in following the laws laid down by the Divine Creator,

he has been able to fashion more perfect forms of plant and animal life. The story of genetics, which deals with the principles of plant and animal breeding, is full of interest. It has to its credit more perfect flowers, fruit of higher yielding qualities and better flavor, fiber crops of superior fiber, sugar crops with a higher content of sugar, crops resistant to plant diseases, crops suitable for dry climates and wet climates, for sour soils and sweet soils, and, in general, for a wide range of soil and climatic conditions. In the same way, genetics has made it possible for us to improve on the types of animals of economic importance in our farming industry.

We are indebted to science for a clearer vision of the great laws of nature and of the methods of the Divine Creator. The men of science, in carrying on their labors in a spirit of reverence and humility, try to interpret the great book of knowledge, in order that the paths of man may fall in more pleasant places and the ways of human society may be in better keeping with the Divine purpose.

With these facts and interpretations of organic evolution left out, the agricultural colleges and experiment stations could not render effective service to our great agricultural industry.

GEOLOGY AND EVOLUTION

By WILBUR A. NELSON

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THE different layers of rock which form the surface of the earth unfold a remarkable story of evolution. These rock layers may be read as clearly as the leaves of a book, and they are the book which tells the true history of the earth; and the buried remains of animal and plant life which they contain likewise show the rise of life and its development on this earth. All forms of life have changed and developed to meet the conditions which have existed on the earth, as it has developed to meet the conditions which have been developing from the beginning of geological time.

Tennessee is an ideal place in which to study and learn the story of the rock layers which have been laid down, from the earliest times in which any life existed up to the present. Life forms suitable for one period of the earth's history proved unsuitable for another period, and so new forms, therefore, evolved through natural causes.

This is not a new study in Tennessee, as geology and its study of buried animal and plant remains has been taught in this state since 1828, at which time Gerard Troost, one of the founders of the Philadelphia Academy of Science, was elected professor of geology at the University of Nashville, and three years later was elected state geologist of Tennessee. From that date to the present time, this science, dealing with the age and study of the earth, and its rocks and the buried life which they contain, has been continuously taught in Tennessee.

Such teaching could not have been carried on through ninety-seven years of time, unless the teaching of evolution had been permitted as it was permitted by our religious ancestors who formed this state.

We know that streams and rivers carry sediment; that muddy waters are full of the soil of some field, washed into a nearby stream by a hard rain, and some such soil, when it once gets into a stream, starts on a long journey to the ocean. Most of the streams in this section are muddy for many months in each year, and this mud, which is the soil washed from our gullied hillsides, in this particular case, goes down the Tennessee River, into the Mississippi River and to the Gulf of Mexico.

We know that at the mouth of the Mississippi River the sediments brought down by this river are deposited so rapidly that land is formed which is extending out into the Gulf of Mexico at the rate of many feet a year. As a rule, these processes of weathering of rocks to produce soil, of erosion of this soil and of deposition of this transported soil through rivers into some nearby sea or ocean, takes place so slowly, as time is generally measured, that we can only see through detailed and scientific observation the results within our own lifetime. But at the delta of the Mississippi River this very process is taking place so rapidly that any one can easily measure it year by year and can understand that these same processes have been taking place through all geologic time, and in each and every part of the world.

We also know that practically all the earth has at some time or other been covered by water and in these ancient seas life has existed, which has left its record to us in fossil form. It must, however, also be understood that large parts of our present water areas were at some period in past geologic time also land areas. These seas have come and gone over limited areas of the earth's surface many times during the geologic history of the earth.

We know that originally the mouth of the Mississippi River was near Cairo, Illinois, and that all the Mississippi Valley, as we now know it, was at that time (which was the close of the Cretaceous

Period) a part of a much larger Gulf of Mexico than the one that now exists. All West Tennessee, during this time, was in a northern extension of the Gulf of Mexico, and the fine china clay deposits of that section were laid down in shallow water at the time tropical plants flourished in that section.

East Tennessee is made up of many layers of rocks, limestone, shale and sandstone, all of which were likewise laid down under water, and many of these layers contain the remains of animal and plant life. Some of the oldest rocks which contain animal life are found in East Tennessee. They are known as Cambrian rocks, and in these rocks occur the first abundant remains of sea form of life. This was the age of the early invertebrates. These rocks are well exposed to the east of Dayton in the East Tennessee Valley region.

Then came the time interval which the geologist calls the Ordovician, the time when primitive fishes, corals and land plants came into existence. Some of these first corals in fossil form have been found in the western edge of Dayton. This time interval was followed by another series of rocks which, in East Tennessee, contain the red iron ore deposits which are used by the iron furnaces of this section. The rocks of this age are known as the Silurian, and during this time life further developed and scorpions and lung fishes came into existence.

The series goes on. Layer after layer of rocks were laid down, each series of which has been given a name by geologists so that they can be easily referred to. Next came the Great Age of Fishes, and their remains are found in the rocks which the geologists call the Devonian and Mississippian series. The black slate, which crops out at the foot of Waldens Ridge, as well as the limestones lying above it, which form the side of the mountain to the west of Dayton, are layers belonging to these series. These rocks are full of the remains of animal life.

Then came the period in which the ancient plants flourished and produced great coal deposits, the age which has been called the Carboniferous. The extensive coal deposits of the Tennessee coal field, the edge of which caps the mountain a few miles west of Dayton, are of this age, and wonderfully preserved plant remains are found in the slates which lie on top of the different coal seams. This is a fact well known by the coal miners of this section. And what has been stated above as to Tennessee is but one illustration of how the different geologic periods passed and life developed over the earth.

And even when this Carboniferous period in the development of the earth has been reached, we are still many millions of years back from the age of man. We must still pass through many

geological time periods, through that age known as the Permian, when land vertebrates first arose, through the Triassic, when reptilian mammals arose, through the Jurassic, when flying reptiles were in existence. This was the Age of Reptiles. Then into the Cretaceous, when flowering plants came into existence, and a great group of the reptiles known as dinosaurs became extinct.

And then we come to that period in the earth's history, at the beginning of which the ancient mammals and birds were first known to exist. Fossil remains show clearly that birds evolved from flying reptiles. This is the Great Age of Mammals. Through this period the modern life forms developed. A period of glacial activity took place, during which five distinct glacial stages existed, one after the other, with four interglacial intervals, and man-like beings came into being at least at the beginning of this time. Such, very briefly, is an account of the evolution of the earth from Cambrian time to the present, with a brief outline of the life forms which existed during these different periods. We know that this took many millions of years, and yet we also know that the earth existed untold millions of years before Cambrian time.

For the formation of the earth and its early stages we must turn to the science of astronomy. The relations of the earth to the stars and the planets are shown in the depths of the heavens, and there must exist in the heavens those cosmic conditions which gave rise to our world and the other planets of our system. Through the telescope and spectroscope the astronomers have solved many of these secrets.

But what of the age of the earth measured in years as we measure other happenings? From the brief outline just given one can see that it has been in existence unknown millions of years, but just how many it is impossible to say.

We can, however, measure back to the more recent events in geological time to the last ice age, before which we know man existed, and get a fairly accurate result, in terms of years. Geologists from the scientific studies they have made have reached the conclusion that from the present time back to the close of the glacial state known as the Wisconsin, the period of the last ice stage, the time interval is between twenty-two thousand and thirty-five thousand years, and man is known to have existed before this time.

One of the most accurate ways in which to measure such time intervals is by measuring and counting the light-colored and dark-colored bands of clay, deposited by the melting of the ice sheet in the fresh water lakes which existed on the edge of those continental glaciers as it retreated to its present position in the north polar regions. Each dark layer of clay was laid down during one winter

and each light layer during one summer. By such detailed studies, it has been determined that it has taken, approximately, 5,000 years for the glaciers of Sweden to melt back 270 miles, and it is further known that this melting back took place 8,500 years ago. We know that the glaciers in North America extended into the northern part of the United States and reached as far south as the Ohio River. We know that now their southern edge lies far to the north in Northern Canada over a thousand miles away. We know that it took approximately 4,000 years for the continental glacier which last covered the New England States to melt back from Hartford, Connecticut, to St. Johnsbury, Vermont. This is only one way of measuring in years some of the more recent geological happenings. There are many other methods that could be given if it were necessary.

In connection with evolution, it is especially of interest to note that the relative ages of the rocks correspond closely to the degrees of complexity of organization shown by the fossils in these rocks. The simpler organisms being found in the more ancient rocks, each type of organism becomes more and more complex as we come nearer to the present day, man and his fossil and cultural remains being no exception.

It, therefore, appears that it would be impossible to study or teach geology in Tennessee or elsewhere without using the theory of evolution.

EVOLUTION AND MENTAL LIFE

By Dr. CHARLES HUBBARD JUDD

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In the normal schools of the state of Tennessee it will, I think, be impossible to obey the law without seriously depriving teachers in training of a proper view of the facts of human mental development. Every psychologist recognizes the fact that the human organs of sense such as the eye and the ear are similar in structure and action to the organs of sense and of the animals. The fundamental pattern of the human brain is the same as that of the higher animals. The laws of learning which have been studied in psychological and education laboratories are shown to be in many respects identical and always similar for animals and man. It is quite impossible to make any adequate study of the mental development of children without taking into account the facts that have been learned from the study of comparative or animal psychology.

It will be impossible in my judgment in the state university as well as in the normal schools to teach adequately psychology or the science of education without making constant reference to all the facts of mental development which are included in the general doctrine of evolution. The only dispute in the field of psychology that has ever arisen among psychologists so far as I know has to do with the methods of evolution. There is general agreement that evolution in some form or other must be accepted as the explanation of human mental life.

Elaborate studies have been made in the field of human psychology dealing with such matters as the evolution of tools, the evolution of language and the evolution of customs and laws. All these studies are based on definitely ascertainable facts and show without exception that a long process of evolution has been going on in the life of man as it is definitely known through historical record and prehistoric remains. In my judgment it will be quite impossible to carry on the work in most of the departments in the higher institutions of the state of Tennessee without teaching the doctrine of evolution as the fundamental basis for the understanding of all human institutions.

Whatever may be the constitutional rights of legislatures to prescribe the general course of study of public schools it will in my judgment be a serious national disaster if the attempt is successful to determine the details to be taught in the schools through the vote of legislatures rather than as a result of scientific investigation.

THE EVOLUTION OF MAN

By Dr. FAY-COOPER COLE

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ANTHROPOLOGISTS accept evolution as the most satisfactory explanation of the observed facts relating to the universe, to our world and all life on it. They hold that the evidence abundantly justifies us in believing that development has been from the simple to the complex and that present forms of life, including man, have been produced from earlier existing forms, but through immense periods of time.

The field of the anthropologist is man, man's body and man's society, and in this study he finds himself working side by side with the biologist and the geologist. For the study of man's body he has worked out a set of instruments and has selected a series of points for observation, by means of which he can accurately describe each

individual of a group, the length, breadth and height of head, the facial proportions, the length of limbs and so on.

In this way the anthropologist determines the average of a group or tribe or race, and to determine its normal variation. Anything strikingly beyond the normal at once becomes the subject of inquiry to determine its cause. In addition to the mathematical description there are added observations—color of skin, shape of teeth, the form of the hair and many others.

On man's skeleton these observations are even more exact and are so definite that given a single skull or skeleton it is possible to tell with considerable certainty the age, sex and race of the individual, while for a series of skeletons the results are definite. The skeletons tell much of man's history, for the articulation of the bones and the lines of attachment of the muscles reveal how he walked, how he held his head and many other details of his life. It also reveals the fact that man presents many variations difficult to explain without referring to similar conditions found in the animal world. To gain further light on these variations the anthropologist works with the anatomist and comparative anatomist and he quickly finds that every human being of to-day possesses many muscles for which there is no apparent use, such muscles as those behind the ears, those going to the tail, the platysma—a muscle going from the chin to the clavicle. These are but a few among many which to-day are functionless in man, but are still in use by certain animals. Going to the human embryo we find these vestiges of an earlier condition much more developed, while others appear for a time and then vanish before birth. Such a case is the free tail possessed by every human embryo a few weeks before its birth.

It is difficult to explain the presence of these useless organs in man unless we believe that some time in his development they were in use.

This study also reveals the fact that man closely resembles certain members of the animal world in every bone and organ of his body. There are differences, but they are differences of degree rather than of kind. Those animals most closely resembling man are the anthropoid apes. A careful study shows that they have specialized in their way quite as much as man has in his, so that while they are very similar, yet it is evidence that man's line of descent is not through any of these anthropoids. It does appear, however, that both man and the other primates have a common precursor, but that the anthropoids must have branched off from the common stock in very remote times. If this is true, then we might hope to find in ancient strata of the rocks some evidences of earlier forms of men, who might perhaps more closely approach the common an-

cestor. This is exactly the case. The geologists have established the relative age of the strata of the rocks, while the paleontologists have made plain the forms of life which lived in the epochs when these strata were deposited.

In the strata laid down at the end of the Pliocene period at least 500,000 years ago, there have been found the bones of a being which appears to be an attempt of nature toward man. In the year 1891, on the island of Java, there were found the bones of an animal which in many ways seems to be intermediate between man and the anthropoids. These bones were found in undisturbed strata forty feet below the surface, at a point where a river had cut through the mountain side. There can be no doubt that these bones were laid down at the time that the stratum was deposited and by studying the associated fauna, consisting of many extinct animals, the age of these rocks is established. These bones were not lying together, but had been scattered over a distance of about forty-five feet by the action of the ancient river which deposited them.

These semi-human bones consisted of a skull cap, a femur and two molar teeth. The skull was low with narrow receding forehead and heavy ridges of bone above the eye-sockets, while a bony ridge extended from between the eyebrows to the top of the head approaching a condition found in the cranium of the anthropoids. The brain capacity of this individual was between 850 and 900 cubic centimeters, or a little more than half of that of modern man. On the other hand, it is half as much again as that of an adult gorilla, and the special development has taken place in those regions whose high development is typical of the brain of man. Hence in this respect this being seems to stand midway between man and the highest anthropoids. The teeth approach the human type and indicate the peculiar rotary mode of mastication of the human which is impossible in animals having interlocking canine teeth. The thigh bone is straight, indicating an upright posture and ability to run and walk, as in man. And the muscle attachments show he was a terrestrial and not an arboreal form. If, as seems probable, these four bones belonged to the same individual, he must have been more man-like than any living ape and at the same time more ape-like than any human known to us. He is known as Pithecanthropus erectus or the erect ape man.

Another find of somewhat similar nature was made only a few months ago in Bechuanaland of South Africa by Professor Dart, of the University of Johannesburg. This find consisted of the skull of an animal well developed beyond modern anthropoids in just those characters, facial and cerebral, which are to be expected in a form intermediate between man and the anthropoids. Neither of

these two beings are, of certainty, directly ancestral to man, but they do seem to indicate that nature at a very early period was making experiments toward man.

Two other fossil beings, found in the early strata of the rocks, also seem to indicate a development toward man. In the strata of the second interglacial period, probably at least 250,000 years ago, there lived a being with a massive jaw, a jaw human in every respect, except that it had no chin and the ramus or upright portion toward the socket was very broad, as in the anthropoids. This jaw is so narrow behind that it is thought the tongue could not have sufficient play to allow of articulate speech. The teeth, although very large, are essentially human with even tops, as in man, while the canines lacked the tusk-like character which they still retain in the apes. This jaw was found in the year 1907 in a sand-pit working near Heidelberg, Germany. It was discovered in place at a depth of nearly eighty feet and lay in association with fossil remains of extinct animals which make possible its dating in geologic time. It is difficult to picture a man from the jaw alone, but this much we can say, the mouth must have projected more than in modern man but less than in the chimpanzee or gorilla. He had a heavy protruding face, huge muscles of mastication, essentially human teeth and he was already far removed from his primate ancestors with large canines; he was nearer to man than to the apes; he was further along the line of evolutionary development than Pithecanthropus erectus, the Java Ape-man, and he lived at a much later period. This being is known as the Heidelberg man.

The second of these two finds which we have mentioned occurred near Piltdown, in Sussex, England. This consisted of the crushed skull of a woman and a jaw which can scarcely be distinguished from that of a chimpanzee. For a time there was much question if the two could possibly belong together, but a more recent find, which occurred about three miles distant from the first, again showed portions of the same type of skull and jaw. The skull is exceedingly thick and its capacity much less than that of modern man, but it is distinctly human, while, as indicated, the jaw approaches that of an anthropoid. Here again we seem to have an approach toward man in very ancient strata.

Toward the end of the second interglacial period in Europe, at least two hundred and twenty-five thousand years ago, we begin to find stone implements which give indication of having been intentionally formed and used by intelligent beings. By the third interglacial period, more than one hundred and fifty thousand years ago, these utensils have taken on definite form and we find thousands of stone axes of crude type scattered over a large portion of central and

southern Europe. We have no fossil remains of man during this third interglacial period, for he then lived in the open and it would not only be by the merest chance that his skeletons might be preserved to us. But when the fourth glacial epoch spread over Europe these men were compelled to make their homes in the shelters and caves of the rocks, and here in the débris around their ancient hearths we can read the record of their home life, and from this period on for a period of at least 50,000 years we can read the record of man's occupancy of Europe as clearly as though we were reading from the pages of a book. Fortunately for the scientists, these people buried their dead and we have preserved for us a considerable number, ranging from children to adult men and women, so there is no guessing as to the sort of man who occupied Europe at this time.

They were massively built, with long arms and short legs, in height they averaged about five feet three for the men and four feet ten for the women or about the same as the modern Japanese. The head was long and narrow; above the eyes was a heavy bony ridge, back of which the forehead retreated abruptly, indicating rather little development of the forebrain. The nose was low and broad, the upper lip projecting, but the jaw was weak and retreating. The head hung forward on a massive chest; this we know because the foramen magnum, the opening by which the spinal cord enters the cranium, was situated further back than is the case in modern man, and the points of articulation with the bones of the neck also show conclusively that the head hung habitually forward. In all cases we find the thigh bone to be curved and this, together with the points of articulation, show that the knee was habitually bent and that this man walked in a semi-erect position. These people, known as the Neandertal race, spread out over the western half of Europe and we now know and have excavated very large numbers of the stations in which they lived. They were men—they were human—but they were much more like the anthropoids in many respects than is modern man. They lived in Europe for a period of at least 25,000 years, probably much longer, when they were displaced by newcomers who pushed in from around the eastern end of the Mediterranean and from Asia. The newcomers, known as Cro-magnon, are a much finer physical type but so closely related to modern man that it is not necessary to describe their physical type; but it is of interest that we can study his home life, his art and his life among certain animals now extinct for a period beginning about 20,000 years ago, and extending down to the coming of the modern races.

Only a few points relating to man and his history have been reviewed, but enough has been said to indicate that the testimony

of man's body, of his embryological life, of his fossil remains strongly points to the fact that he is closely related to the other members of the animal world, and that his development to his present form has taken place through immense periods of time.

From the above it seems conclusive that it is impossible to teach anthropology or the prehistory of man without teaching evolution.

EVOLUTION AND RELIGION

By Dr. KIRTLEY F. MATHER

PROFESSOR OF GEOLOGY, HARVARD UNIVERSITY

SUCH facts as I have stated can be explained only by the conclusion that man has been formed through long processes of progressive development, which when traced backward through successively simpler types of life, each living in more remote antiquity, lead unerringly to a single primordial cell. The facts ascertained by natural science are obviously incomplete; the record of the rocks by no means tells the whole story. Man not only has an efficient and readily adaptable body, he also possesses a knowledge of moral law, a sense of rightness, a confidence that his reasoning mind finds response in a rational universe, and a hope that his spiritual aspirations will find increasing answer in a spiritual universe. Such things as these can not be preserved in the fossil record, yet their presence must be accounted for. Nor have we a direct record of whence came the first living cell. The inference is unmistakable that the material substances from which living cells were first constructed were previously present among the rocks and minerals of the earth. All the necessary ingredients were certainly present in the outer shell of the youthful earth of even pre-Archeozoic time. But life is something more than matter. Living creatures are characterized by vital energy, something about which we really know very little, but something which is absolutely indispensable to every living creature. T. C. Chamberlin, the dean of American geologists, closes his volume on the origin of the earth with the following sentence: "It is our personal view that what we conveniently regard as merely material is at the same time spiritual, that what we try to reduce to the mechanistic is at the same time volitional, but whether this be so or not, the emergence of what we call the living from the inorganic, and the emergence of what we call the psychic from the physiologic, were at once the transcendent and the transcendental features of the earth's evolution." With this conclusion I am in hearty accord. I believe that life as we know it is but one

manifestation of the mysterious spiritual powers which permeate the universe. The geologic factors assembled in the primitive earth provided an environment within which the spiritual could manifest itself in the material. The form which it should assume may have been largely determined by that environment; the primitive cell was the result. Thus, in truth, was man made from the dust of the ground.

Again, the record of the rocks tells nothing except by inference of the previous state of the mineral matter of which the earth is made. Several theories, varying from one another in greater or less detail, are now under consideration by geologists and astronomers in their attempt to understand the actual beginnings and the antecedents of the earth and its fellow planets in the solar system. So far as we now know all the planets, suns and stars within range of our telescopes are composed of the same sort of matter, reducible upon analysis to about eighty different elements, nearly all of which are present in the earth. In other words, it is a fair sample of the material substances of the entire universe. Science has not even a guess as to the original source or sources of matter. It deals with immediate causes and effects, not at all with ultimate causes and effects. For science there is no beginning and no ending; all acceptable theories of earth origin are theories of rejuvenation rather than of creation from nothing. Indeed, there is some evidence for the prevalent view that our sun had had at least one earlier generation of planets in its train before the disturbing effect of the close approach of another star caused the reorganization of part of its matter into our present solar system. Conversely, it is probable that at some remotely distant date in the future this group of planets, on one of which we live, will be similarly destroyed by another rejuvenating disturbance and still another cycle of planetary organization may take place.

But none of these facts is really in any way disturbing to the adherent to Christianity. Not one contradicts any teaching of Jesus Christ known to me. None of them could; for his teachings deal with moral law and spiritual realities. Natural science deals with physical laws and material realities. When men are offered their choice between science, with its confident and unanimous acceptance of the evolutionary principle, on the one hand, and religion, with its necessary appeal to things unseen and unprovable, on the other, they are much more likely to abandon religion than to abandon science. If such a choice is forced upon us, the churches will lose many of their best educated young people, the very ones upon whom they must depend for leadership in coming years. Fortunately, such a choice is absolutely unnecessary. To

say that one must choose between evolution and Christianity is exactly like telling the child as he starts for school that he must choose between spelling and arithmetic. Thorough knowledge of each is essential to success—both individual and racial—in life.

Although it is possible to construct a mechanistic evolutionary hypothesis which rules God out of the world, the theories of theistic evolution held by millions of scientifically trained Christian men and women lead inevitably to a better knowledge of God and a firmer faith in his effective presence in the world. For religion is founded on facts, even as is the evolutionary principle. A true religion faces the facts fearlessly, regardless of where or how the facts may be found. The theories of evolution commonly accepted in the scientific world do not deny any reasonable interpretation of the stories of divine creation as recorded in the Bible, rather they affirm that story and give it larger and more profound meaning. This, of course, depends upon what the Bible is and what the meaning and interpretation of the stories are to each individual. I have been a Bible student all my life, and ever since my college days I have been intensely concerned with the relations between science and the Bible. I have made many addresses and have written several articles upon this subject. I have many times lectured to Biblical students, such as those in the Boston University School of Religious Education.

It is obvious to any careful and intelligent reader of the book of Genesis that some interpretation of its account must be made by each individual. Very evidently, it is not intended to be a scientific statement of the order and method of creation. In the first chapter of Genesis we are told that man was made after the plants and the other animals had been formed, and that man and woman were both created on the same day; in the second chapter of Genesis we read that man was formed from the dust of the ground before plants and other animals were made, that trees grew until fruit was upon them, that all the animals passed in review before man to be named, and then after these events woman was made. There is obvious lack of harmony between those two Biblical accounts of creation so far as details of process and order of events are concerned; they are, however, in perfect accord in presenting the spiritual truth that God is the author and the administrator of the universe. And that is the sort of truth which we find in the Bible. It is a text-book of religion, not a text-book of biology or astronomy or geology. Moreover, it is just exactly the Biblical spiritual truth concerning God which rings clearly and unmistakably through every theory of theistic evolution. With it modern science is in perfect accord.

There are a number of reasons why sincere and honest Christians have recently come to distrust evolution. These reasons must be understood and discussed frankly before the world will believe that science and religion are not in conflict. Some of the opposition to evolutionary science results from failure to read the Bible. Too many people who loudly proclaim their allegiance to the Book know very little about what it really contains. The Bible does not state that the world was made about six thousand years ago. The date 4004 B. C., set opposite Genesis 1: 1 in many versions of the Bible, was placed there by Archbishop Ussher only a few centuries ago. It is a man's interpretation of the Bible; it is in the footnotes added recently. It is not a part of the book itself. Concerning the length of earth history and of human history the Bible is absolutely silent. Science may conclude that the earth is a hundred million or a hundred billion years old; the conclusion does not affect the Bible in the slightest degree. Or if one is worried over the progressive appearance of land, plants, animals and man on the successive six days of a "creation week," there is well-known Biblical support for the scientists' contention that eons rather than hours elapsed while these things were taking place. "A day in the sight of the Lord is as a thousand years, and a thousand years as a day." Taking the Bible itself as an authority dissipates many of the difficulties which threaten to make a gulf between religion and science. The fact that the seventh day was stated to be a day of rest has no bearing upon the length of the other days. I have no doubt that the man who made that chapter of Genesis had in his mind days of twenty-four hours each, but I reserve for myself the right to make my own interpretation of the meaning of words, as does every Christian, be he liberalist, trivialist or modernist.

Another of the reasons for the modern distrust of science in the religious world is the idea that evolution displaces God. Many seem to think that when the scientist enthrones evolution as the guiding principle in nature he dethrones God, that the two words are somehow synonymous, that there is not room for both and one must go. But the facts are as follows: Evolution is not a power, nor a force; it is a process, a method. God is a power, a force; he necessarily uses processes and methods in displaying his power and exerting force. Many of us believe that science is truly discovering in evolution the processes and the methods which God, the spiritual power and eternal force, has used and is using now to effect his will in nature. We believe we have a more accurate and a more deeply significant knowledge of our Maker to-day than had the Hebrew patriarchs who thought a man could hide from God in a garden or who believed that God could tell man an untruth. (Gene-

sis 2:17 states that God told man he would surely die if he ate the fruit of the tree of knowledge; man ate, he did not die, God knew he would not die therefore.)

Again there is the widespread misconception that if one accepts the evolutionary process as the method which God used, he will find himself in a moral dilemma. Regardless of sect or creed, all followers of Christ must accept his teaching that the law of life is love, that service to others is the true guiding principle, that self-sacrifice even to death is the best trait a man can display. To many evolution means the survival of the fittest in the struggle for existence; and that is taken to imply that the selfish triumph, the most cruel and bloodthirsty are exalted, those who disregard others win. Obviously this is the very antithesis of Christianity; both principles can not be true; one must be false. The Christian needs not to be told which of the two it is. Here is a real reason for opposition to evolution; men are not driven from it by the fear of discovering that their bodies are structurally like those of apes and monkeys; it doesn't bother us to discover that we are mammals, even *odorous* mammals—"by the sweat of his brow must man earn food," states the Bible. It *does* bother us to find the implication that the law of progress has thus apparently been opposed to the love of Christ. But here are the facts. It has been my privilege as a geologist to read the record in the rocks; knowing the ages of the rocks has led to better knowledge of the Rock of Ages; I have watched the procession of life on the long road from the one-celled bit of primitive protoplasm to the present assemblage of varied creatures including man. At times of crisis in the past it was rarely selfishness or cruelty or strength of talon and of claw that determined success or failure. Survival values at different times have been measured in different terms. Ability to breathe air by means of lungs rather than to purify the blood by means of gills meant success in escaping from the water to the land. Love of offspring and tender care for the young gave the weak and puny mammals of long ago the ability to triumph over much stronger and more powerful reptiles like the dinosaur. Especially in the strain that leads to man can we note the increasing spread of habits of cooperation, of unselfishness, of love. The survival of the "fit" does not necessarily mean either the survival of the "fittest" or of the "fightingest." It has meant in the past, and I believe it means to-day and to-morrow, the survival of those who serve others most unselfishly. Even in evolution is it true that he who would save his life must lose it. Here, if nowhere else, do the facts of evolution lead the man of science to stand shoulder to shoulder with the man of religion.

Another difficulty arises from our present limitations of knowledge. If man has evolved from other forms of animal life by the continuous process of evolution it is asked how can there be any difference between him and them, how can we believe that he has an immortal soul. Again, the appeal to facts makes it clear that somehow out of the continuity of process real differences have emerged. When the cow pauses on the hillside to admire the view, when the dog ceases to bay at the moon in order to construct a system of astronomy, then and not till then will we believe that there are no differences between man and other animals. Even though we may not understand how these differences arose, the facts are there; knowledge and mystery exist side by side; mystery does not invalidate the fact. Men of science are working on those very problems. They have not learned—and may never learn—how God breathed a living soul into man's body. If they should discover that process and the method used, God will still be just as great a power. In the image of God can not refer to hands or feet, heart, stomach, lungs. That may have been the conception of Moses, it certainly was not the conception of Christ who said that God is spirit and proclaimed that man must worship Him in truth. It is man's soul, his spirit, which is patterned after God the Spirit.

It is the business of the theologian, not the scientist, to state just when and how man gained a soul. The man of science is keenly interested in the matter, but he should not be blamed if he can not answer questions here. The theologian must tell when the individual gets his soul, whether at the moment of conception or when the unborn babe first stirs within the womb or at the moment of birth or at the first gleam of intelligent appraisal of his environment and how he knows this.

Men of science have as their aim the discovery of facts. They seek with open eyes, willing to recognize it, as Huxley said, even if "it sears the eye-balls." After they have discovered truth, and not till then, do they consider what its moral implications may be. Thus far, and presumably always, truth when found is also found to be right, in the moral sense of the word. Men of religion seek righteousness; finding it they also find truth. The farther along the two avenues of investigation the scientist and the theologian go, the closer together they discover themselves to be. Already many of them are marching shoulder to shoulder in their endeavor to combine a trained and reasoning mind with a faithful and loving heart in every human individual and thus to develop more perfectly in mankind the image of God. Neither the right kind of mind nor the right kind of heart will suffice without the other. Both are needed if civilization is to be saved.

As Henry Ward Beecher said, forty years ago, "If to reject God's revelation of the Book is infidelity, what is it to reject God's revelation of himself in the structure of the whole globe?" With that learned preacher men of science agree when he stated that "the theory of evolution is the working theory of every department of physical science all over the world. Withdraw this theory and every department of physical research would fall back into heaps of hopelessly dislocated facts, with no more order or reason or philosophical coherence than exists in a basket of marbles, or in the juxtaposition of the multitudinous sands of the seashore. We should go back into chaos if we took out of the laboratories, out of the dissecting rooms, out of the field of investigation, this great doctrine of evolution." Chaos would inevitably destroy the whole moral fabric of society as well as impede the physical progress of humankind.

THE PROGRESS OF SCIENCE

By Dr. EDWIN E. SLOSSON

SCIENCE SERVICE, WASHINGTON

A CRAZY EXPERIMENT

I SUPPOSE every scientific man occasionally tries experiments that he would not care to confess to his colleagues. Crazy ideas will pop up in the best regulated brains from some subconscious cellar and sometimes they are tried out, on Saturday afternoon when there is nobody else around, just to see what will come of them. They do not appear in the published reports, unless they happen to succeed, in which case the audacious experimenter will claim credit for foresight in undertaking an operation that ordinary minds would have condemned in advance as absurd.

Now it is interesting to observe that such erratic and irrational experimentation is distinctly recommended by the philosopher who laid down the laws of experimental science that have in the three centuries since accomplished such amazing achievements.

Lord Bacon, after listing in his precise and orderly manner all the various ways that we may be guided in our researches by theory, observation and previous experiment, concludes quite unexpectedly by adding a new category, what he calls the experiments of a madman and defines as follows:

"When you have in mind to try something not because reason or some other experiment leads you to it but simply because such a thing has never been attempted before."

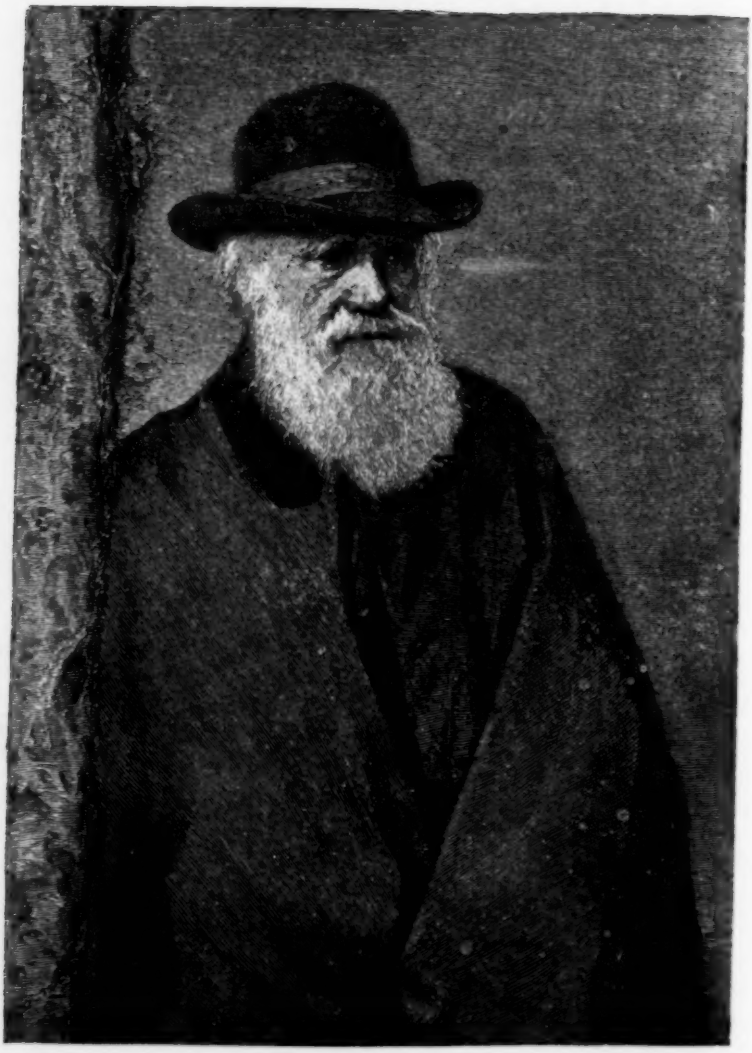
"The leaving I say, of no stone in nature unturned, for the magnalia of nature generally lie out of the common roads and beaten paths so that the very absurdity of the thing may sometimes prove of service. But if reason go along with it, that is, if it be evident that an experiment of this nature has never been tried, then it is one of the best ways and plainly shakes the folds out of nature."

The example Bacon gives of such unprecedented experiments is of peculiar interest to us:

"But of what I may call close distillation no man has yet made trial. Yet it seems probable that the force of heat, if it can perform its exploits of alteration within the enclosure of the body, where there is neither loss of the body not yet means of escape, will succeed at last in handcuffing this Proteus of matter and driving it to many transformations; only the heat must be so regulated and varied that there be no fracture of the vessels.

"No one should be disheartened or confounded if the experiments which he tries do not answer his expectation. For though a successful experiment be more agreeable, yet an unsuccessful one is often times no less instructive. And it must ever be kept in mind (as I am continually urging) that experiments of Light are even more to be sought after than experiments of Fruit."

What Bacon was "continually urging" that "experiments of Light"—those that lead to the enlightenment on fundamental principles—"are even



Ch. Darwin

more to be sought after than experiments of Fruit"—those that bring practical results—needs more than ever to be kept in mind at the present day when public and employers are impatient of research that does not bring immediate and profitable returns.

So it is worthy of notice that the example that Bacon cites, as the experiment of a madman, that is, destructive distillation, has been peculiarly productive of both light and fruit. Applied to coal it has given us coke for metallurgy, gas for cities, and shops and coal tar products of innumerable variety and inestimable value. Applied to petroleum in the cracking process it has increased the yield of gasoline by some 2,000,000 gallons a day. By this "handcuffing this Proteus of matter and driving it to many transformations" Light has been thrown upon the structure of the molecule and the chemistry of life.

TAKE YOUR VITAMINS IN FOOD

"VITAMINS should be sought in the garden, or in the market, and not in the drug store," says Dr. D. Breese Jones, chemist in charge of Protein Investigations of the Bureau of Chemistry, of the Department of Agriculture, in a recent report giving a summary of our present knowledge of vitamins. "In cases of suspected vitamin deficiency in the diet," according to the report, "corrective measures should be taken through the use of suitable natural foodstuffs, and not through commercial vitamin preparations, many, if not most of which are worthless."

Vitamins play a very different rôle in nutrition from the other food constituents. They are essential to growth, health and life, but they contribute neither energy nor tissue building material. Their function has been likened to that of the spark plug in a gas engine. They are often referred to as the accessory food factors.

People and animals are unable to provide vitamins within their bodies. Lack of sufficient vitamins in the diet is soon followed by serious consequences. Young animals will fail to grow normally, and adults will rapidly decline in weight and develop certain characteristic affections known as deficiency diseases.

It is now known that there are at least five vitamins, designated as A, B, C, D and E, and it is probable that others will be discovered. The absence from the diet of any one of the five will produce certain characteristic effects.

Vitamin A, for instance, is essential to growth and health. Young animals on a diet devoid of it soon stop growing and lose weight. Their vitality becomes lowered and they are less able to resist disease and infection, particularly of the respiratory tract. In many animals, as rats, dogs, rabbits and poultry, and also in man, a characteristic affliction of the eyes results. The administration of Vitamin A prevents or promptly cures this affliction. Growing animals require more of it than do adults. It is abundant in butter, cream, cheese, whole milk, egg yolk, the liver, heart and kidneys of animals, in spinach, lettuce, cabbage, tomatoes, carrots, sweet potatoes, parsnips and green peas, and is present in varying quantities in many other foods. Cod liver oil is rich in this vitamin and the liver oils of some other varieties of fish contain it.

Vitamin B is also necessary for the maintenance of life and health at all ages. Lack of it promptly results in loss of appetite and arrest of growth, followed by various functional disorders and, finally, death. This

Wide World Photos

MME. PIERRE CURIE

Professor of general physics and director of the Curie Laboratory of the Radium Institute of the University of Paris, addressing a scientific meeting at the university.

DR. FLORENCE R. SABIN

Since 1903 connected with the department of anatomy of the Johns Hopkins University, who has become a member of the Rockefeller Institute for Medical Research, New York City. Dr. Sabin was this year elected a member of the National Academy of Sciences, this being the first time the honor has been conferred on a woman.

is the most widely distributed of all the vitamins. It is abundant in green plant tissues. Cereals and seeds contain it, the germ of the seed being an exceptionally good source. Yeast and wheat germ are standard sources of this vitamin in experimental work. Roots and tubers as a class are good sources of it, and it is especially abundant in tomatoes. Most fruits and nuts are well supplied with it. Meat is reported to contain Vitamin B. The heart appears to be the richest in this vitamin, and the liver and kidneys have only slightly lower values. The flesh of the chicken, turkey, duck and guinea fowl, however, are deficient in it.

Notwithstanding the wide distribution of vitamin B in foodstuffs, certain classes of people, as soldiers, sailors, travelers, infants and others, living on restricted or artificial diets, have suffered serious consequences because of a lack of it. Beriberi, one of the diseases produced by the absence of this vitamin, is most commonly found among those living chiefly on polished rice. Removal of the germ and seed coats or bran of cereals

takes away practically all the vitamins. Consequently, polished rice, patent white flour, and degerminated corn meal are practically devoid of vitamins.

Vitamin C is sometimes known as the "anti-scurvy vitamin," because a lack of it in the diet causes scurvy, a disease which has been prevalent among sailors, soldiers, explorers and others compelled to live for long periods on dried and preserved foods.

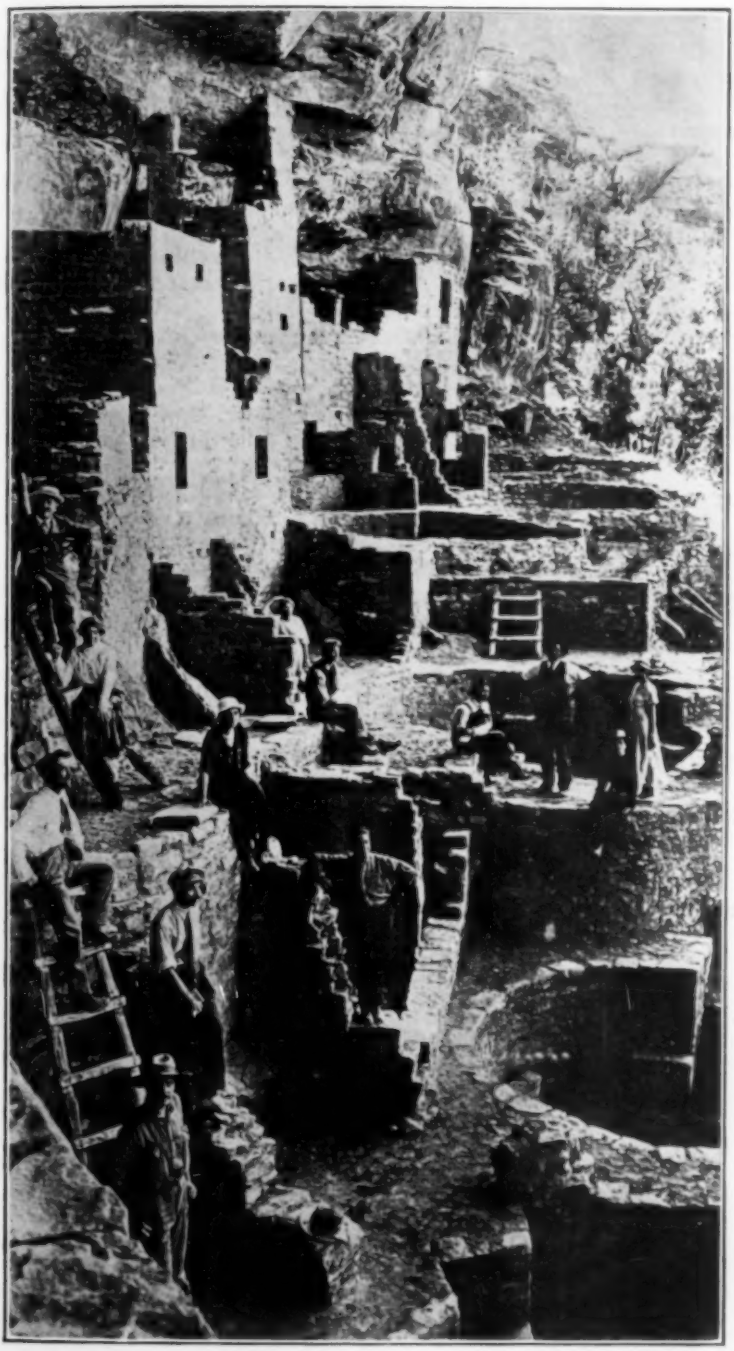
Even in the late World War, Wilcox states, there were more than 11,000 cases of scurvy in the British colonial troops in Mesopotamia during the last half of 1916. Farm animals are not very susceptible to scurvy and it is considered that chickens and pigs are not harmed by a lack of Vitamin C in their diet. The best sources of Vitamin C are lemons, oranges, tomatoes, cabbage, lettuce, spinach, green beans and peas, and turnips. Most green vegetables, fruits, roots and tubers contain Vitamin C in varying quantities. Meat, excepting the internal organs, is a poor source. It has been reported that oysters contain it in abundance. Milk contains it to some extent, but is an uncertain source. This vitamin is easily destroyed by the processes used in the preparation of many food products. Orange juice or tomato juice is sometimes given to babies reared on artificially prepared food as a precaution against scurvy.

Vitamin D seems to control to a large extent the utilization of lime and phosphorus in the formation of bone by the animal organism. Its absence in the diet will cause rickets, a disease characterized by enlargement of the joints, softening of the bones and subsequent bending. Hess states that "Rickets is the most common nutritional disease occurring among children of the temperate zone, fully three fourths of the infants in the great cities, such as New York, show rachitic signs in some degree." This disease can be prevented by a proper diet. It can also be prevented or cured by administering cod liver oil, which contains vitamin D in abundance, or by exposure to the ultra-violet rays of sunlight or the mercury lamp, if the diet contains the other necessary food elements in adequate quantity. This vitamin has been found in egg yolk and to some extent in milk. Coconut oil contains it in slight amount. As yet but little has been learned of the general distribution of Vitamin D in the plant world.

Vitamin E, the anti-sterility vitamin, was originally referred to as Vitamin X, because of the uncertainty as to whether or not it should be classed as a vitamin. Most of the knowledge concerning it has been obtained within the last two years. It has been shown that rats reared on synthetic food mixtures containing fat, carbohydrate, protein, salts and Vitamins A and B, grow well and have every appearance of health, but exhibit complete sterility, affecting both males and females. When small quantities of natural food stuff were added to the ration of these same rats, there resulted in many cases normal sized litters of vigorous young. An excess of Vitamin E can not increase fertility beyond normal limits.

ANEMIA

THE discovery of anemia or pale blood in laboratory animals that is "quite identical with a similar condition that occurs in man," after removal of the stomach, and new data that may lead to the prevention and cure of the condition have resulted from an important experiment in the physiology department of the University of Chicago conducted by Dr. A. C. Ivy and his assistants and made public recently.



International News Reel Photos

MESA VERDE CLIFF DWELLINGS

The largest of the prehistoric ruins in Southwestern Colorado.

Dr. Ivy and his colleagues completely removed the stomach from experimental animals and joined the small intestine to the esophagus or gullet so that food when swallowed entered the small intestine directly. They found that dogs can grow fat and live happily for months on a specially prepared diet of cooked ground meat, bread and milk.

Finally an anemia developed that is said to be the same as that which causes the unnatural paleness of skin in anemic human beings. "It appears from this observation," according to a report on his work by Dr. Ivy, "that the stomach is in some way concerned with the metabolism of iron, a substance that is necessary for the normal functioning of the blood and tissues. Experiments are now being conducted to discover a means by which this anemia can be prevented and cured."

Additional facts illuminating the whole study of gastric secretion have resulted from this experiment. It has been found that the mechanical distension of the stomach by food is one of the causes of gastric secretion. The simple distension of the stomach with a toy balloon will cause the gastric glands to secrete, Dr. Ivy has shown.

Meat contains a substance which will excite the gastric glands when introduced into the stomach. Other foods contain very little if any of this stimulating substance. Fats inhibit or slow up gastric secretion. Partially or completely digested foods acting in the intestine cause the stomach to secrete its digestive juice.

Dr. Ivy and his assistants have been successful in transplanting a part of the stomach and pancreas under the skin in the same experiment. After a meal is eaten the transplanted stomach and pancreas secrete. According to Dr. Ivy, this shows that there is something in the blood after a meal is eaten that causes these organs to secrete digestive juices.

By using the transplanted stomach they have been able to show that during hunger some change occurs in the blood which causes the stomach to contract, resulting in the so-called hunger pains or pangs.